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# BIOLOGY AND HABITS OF THE STRAWBERRY LEAF ROLLER, ANCYLIS COMPTANA (FROEL.), IN NEW JERSEY [1]

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## INTRODUCTION

A severe outbreak of the strawberry leaf roller (*Ancylis comptana* Froel.) [3] occurred on a 40-acre strawberry field in the vicinity of Hartford, N. J., in 1920, and although extensive spraying was done the results were negative. The available literature on the strawberry leaf roller at that time furnished very meager information as to its biology and none concerning the feeding habits of the young larvae. The biology of the insect in New Jersey was, therefore, investigated for the purpose of finding a vulnerable stage in the insect's development.

## HISTORICAL REVIEW

Probably the first reported injury by the leaf roller in this country is that mentioned by Riley (*8*) [4] as occurring in northern Indiana in 1866. Riley observed the insect in 1868 and concluded that it was two brooded and passed the winter in the pupal stage. Observations made in Kentucky in 1890 by Garman (*7*) indicated that the leaf roller was four brooded and passed the winter in the larval stage, maturing the following spring. Somewhat more complete accounts of the insect and its habits were furnished by Stedman (*10*) in 1901, by Smith (*9*) in 1909, and by Webster (*11*) in 1918. According to Smith, who observed the insect in New Jersey for many years, the eggs are laid on the underside of the leaves and the larvae wander to the upper surface as soon as hatched and, for a day or two, feed openly on the upper surface. Smith also stated that the winter is passed by the leaf roller in the pupal stage. Stedman, reporting from Missouri, and Webster, from Iowa, state that the larvae, as soon as they hatch, spin silken webs under which they feed. Stedman found the young larvae on the upper surface, and Webster found them on both surfaces, but he states that the under surface of the leaves is preferred. No mention of the hibernating habits is made by Stedman, but Webster states that in Iowa the winter is passed by the leaf roller as a mature larva which in early spring pupates without feeding. Other writers have frequently reported the presence and destructiveness of the leaf roller, and recently Dunnam (*1*) has published the results of a season's observations in Iowa on its life history and control.

Although many conflicting observations regarding the life history of the leaf roller were recorded by the early workers, the more recent reports, especially those of Webster, have been substantiated by the

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[2] At the time these studies where made Dr. Fink was assigned to the Riverton, N. J., laboratory of the Division of Truck Crop Insects.

[3] Order Lepidoptera, family Olethreutidae, subfamily Eucosminae.

[4] Reference is made by number (italic) to Literature Cited, p. 557.

writer in his studies of the insect in New Jersey. In the following pages many additional facts regarding the habits and biology of the leaf roller are recorded.

## DISTRIBUTION AND MEANS OF DISPERSAL

Of European origin, the strawberry leaf roller has been known to exist in this country for more than half a century. From the records available it appears that this species is distributed in the North from the Atlantic coast to the Pacific coast and from Canada southward to Virginia, Kentucky, Kansas, Colorado, and California, which, with the exception of Louisiana and Arkansas, form the southern limit of distribution. It seems to be most destructive in the upper Mississippi Valley and in some of the Atlantic Coast States. There are no records of its occurrence in most of the Southern States.

Local infestations of strawberry fields are often caused by the flight of adults from infested fields. On the other hand, infestations of widely separated localities may be brought about by the importation of infested plants. Plants obtained from an infested region may harbor both eggs and larvae. A careful grower may notice the rolled or folded leaves that harbor the more mature larvae and remove them before setting the plants in the field. It is, however, practically impossible to discover all the very young larvae or eggs that may be on the plants.

## NATURE OF INJURY

The attack of the strawberry leaf roller is confined entirely to the leaves of the plant. Besides the actual injury to the foliage caused by the feeding of the larvae, the normal life of the plant may be disturbed by the folding or rolling of the leaves. The withering of the leaves results in malnutrition of the exposed fruit, which also withers and shrivels. In severe infestations the foliage of infested strawberry fields looks as though it were scorched or burned, and the fruit becomes deformed and small in size and all tends to ripen at one time.

## BEDS

The greatest amount of injury to old strawberry beds is apparent during June at the end of the first generation of larvae. The greatest injury to newly set fields is caused by larvae of the second and third generations during the summer. In the fall, owing to the heavy growth in foliage of both old and new strawberry plants, injury is not severe unless accompanied by dry weather.

Growers in localities suffering from depredations by the strawberry leaf roller believe that the losses from reduced yield and poor quality of fruit may amount to as much as 50 per cent of the normal crop.

## FOOD PLANTS

Fortunately the food plants of the strawberry leaf roller are very limited, and injury in this country is confined mostly to the strawberry, raspberry, and blackberry. However, the writer has found it feeding on clover growing in a strawberry field. Fernald (*3, p. 50*) mentions the following as European food plants: *Potentilla opaca*, *P. verna*, *P. cinerea*, *Dryas octopetela*, *Poterium sanguisorba*, *Thymus serpyllum*, and Teucrium.

## SYNONYMY

This species was first described by Froelich (*6, p. 99*) in 1828, as *Tortrix comptana*. Specialists working on this group have since placed it in the genus Ancylis. Its synonymy includes the following names:

**Ancylis comptana** (Froelich).
*Tortrix comptana* Froelich, 1828.
*Phoxopterix comptana* Duponchel, 1844.
*Anchylopera comptana* Wilkinson, 1859.
*Grapholitha* (*Phoxopteryx*) *comptana* Heinemann, 1863.
*Grapholitha conflexana* Walker, 1863.
*Anchylopera fragariae* Walsh and Riley, 1869.
*Ancylis comptana* Fernald, 1903.

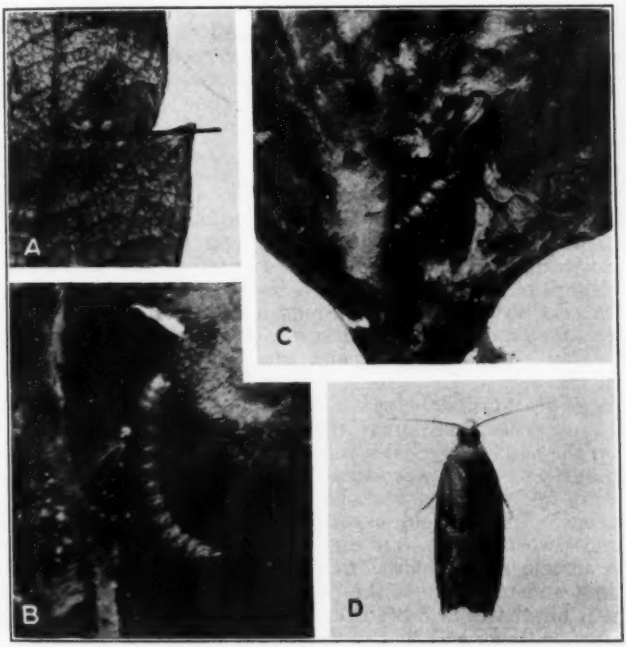


FIGURE 1.—The strawberry leaf roller: A, Eggs on the underside of a strawberry leaf; B, folded leaf opened to show a larva; C, a leaf opened to show the pupa; D, the moth. All × 4

## THE MOTH

### DESCRIPTION

The moths average slightly over 1 cm across the outstretched wings. The general ground color is light to dark reddish brown. The fore wings are reddish brown streaked with darker brown and white lines. When the moth is at rest there can be seen on the base of the folded wings a dark area forming a conspicuous deeper brown patch across the middle of the back. The hind wings are dark gray, and both wings have long fringes. (Fig. 1, D.) For a more detailed description, furnished by Fernald, the reader is referred to Forbes (*5*).

### FLIGHT AND PROTECTIVE HABITS

If the moth is disturbed it flies swiftly and erratically from row to row and when it alights on the foliage runs rapidly and secretes itself a short distance from where the flight ended. The moth is probably protected to some extent by the coloration of its fore wings, since the dark-brown spot upon a reddish background blends with the surrounding foliage. When food plants are abundant, the insects do not fly far. Some individuals, however, may find their way to considerable distances and infest new fields. Careful measurements of the distance covered by the moths in a single flight showed a range of from a few yards to 50 feet.

### EMERGENCE, COPULATION, AND OVIPOSITION

The spring adults emerge from the pupae formed from overwintering larvae. The date of emergence is governed largely by weather conditions. In New Jersey, in 1920, moths were observed in strawberry fields the latter part of April; in 1921 they appeared in the fields March 28. In the latter year the month of March was abnormally warm.

Mating was seldom observed in the field. Of several hundred pairs kept in the breeding house for egg records only about six pairs were seen in copula. This number was sufficient, however, to indicate the method and duration of mating. As is the case with many other moths during copulation, the body of the male is extended in line with that of the female and faces in the opposite direction. One pair of moths was observed in copula for over an hour and a half, other pairs for 20 minutes. In the cases observed copulation occurred within a day after emergence, and eggs were deposited three days after mating.

The eggs are normally deposited on the undersides of the strawberry leaves, occasionally upon the upper surface of the leaves, and rarely on the stems. Females confined in cages deposited their eggs on both surfaces of the leaves and sometimes deposited as many as 20 or more upon a single leaf, but this may be attributed to their confinement. In the field usually but one egg is laid on a leaf. Sometimes two or three, but rarely more, are found upon a single leaf. A female may deposit from 20 to 30 eggs during its active oviposition and may repeat the process at intervals of two to three days until all the eggs have been deposited. Oviposition in cages takes place at dusk, and this apparently is true also under field conditions, since at sundown the moths appear to be most active in their flights about the infested fields.

### LONGEVITY

Determinations of the longevity of moths are based upon records of paired individuals used for breeding purposes. The records show that the average life of the male is eight days, but the average life of the female varies somewhat with the season. As shown in Figure 2, the average length of life based on 47 females in April is 17 days; of 34 females in June, 15 days; and 55 females in August, 12 days. Generally it appears that cooler weather is favorable to longevity in this species.

Dunnam (*1*) records the average life of 30 females as 14.73 days and of 25 males as 16.56 days. He does not state, however, the months in which the data were recorded.

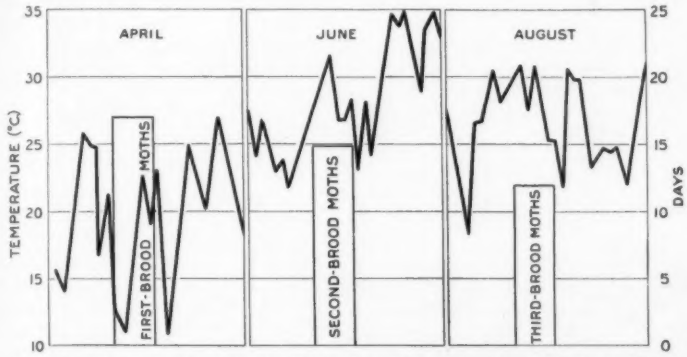


FIGURE 2.—The average length of life of the female moth of the strawberry leaf roller for each of the three broods, and the maximum daily temperatures for the same periods, Riverton, N. J., 1921

## PARTHENOGENESIS

To ascertain whether parthenogenesis occurs, unmated and mated females were confined in separate cages with suitable food plants. From 10 unfertilized females thus confined no eggs were recovered, but in cages containing fertilized females kept under similar conditions oviposition occurred. Dunnam (*1*) states that some unfertilized females in his cage experiments deposited infertile eggs.

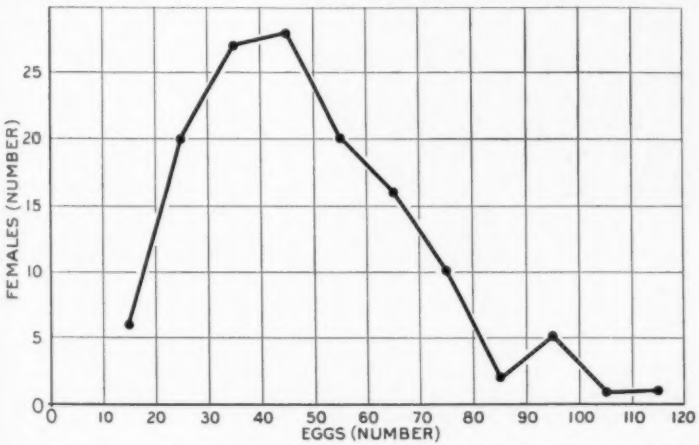


FIGURE 3.—Numbers of eggs deposited by 136 females of the strawberry leaf roller, grouped into classes and each class represented by its mid-point. Riverton, N. J., 1921

## FECUNDITY

There is considerable variation in the number of eggs that a moth may deposit. Records were kept of the number of eggs deposited by 136 moths, and these are represented graphically, in Figure 3, in which

it is shown that the greatest number of females deposited from 20 to 70 eggs. The average number of eggs deposited by the moths in different months of the year was found to be as follows: April, 38.6; June, 59.5; August, 52.5. These figures are based on 47, 34, and 55 females, respectively. Webster (*11*) states that the average number of eggs laid by 35 females was 72.9. Dunnam (*1*) found that the number of eggs laid per day ranged from 1 to 67 and that the average number laid per female was 85.1.

## THE EGG

### DESCRIPTION

The egg viewed from above is oval, and has an irregular basal surface which is attached to the leaf. (Fig. 1, A.) As light plays upon the reticulated surface there is a display of iridescence. The egg when first laid is pale green, blending with the natural color of the lower surface of the leaves. With the development of the embryo the color changes to yellowish, which indicates that hatching is imminent. The average dimensions of the eggs measured were 0.378 by 0.648 mm.

FIGURE 4.—Funnel-shaped silky retreat constructed by a young larva of the strawberry leaf roller between two veins on the under surface of a leaf. × 2

### INCUBATION

The time required for the incubation of the egg depends upon seasonal conditions. In April the eggs hatched in from 14 to 17 days, during June and July in from 6 to 8 days, and during August in from 5 to 9 days. Temperatures for three of these months are shown in Figure 2. Webster (*11*) found that in Iowa during May, 1919, the eggs hatched in 11.1 days and during July and August, 1915, in from 3 to 12 days. Dunnam (*1*) does not mention the month during which his experiments were conducted but states that their "optimum for development" seems to be eight days at 73.02° F.

## THE LARVA

### RETREATS AND FEEDING AREAS

After emerging from the egg the larvae move slowly over the under surface of the leaf, feeding a little until a suitable place over which to construct their protective silky retreat is found. This tubelike shelter is generally constructed in the angle formed by two veins (fig. 4), at

the base of the leaf, or very often along the side of a vein (fig. 5). The small larvae gradually construct an overhead covering by spinning threads of silk from side to side. This retreat is at first not much longer than the young larva, but as the feeding area is extended the

FIGURE 5.—Feeding areas and the retreats constructed by young larvae of the strawberry leaf roller on the underside of a strawberry leaf. × 2

tubelike tent is lengthened and broadened to accommodate the insect's growth. Within three or four days the retreat resembles a little funnel, with the narrower end toward the base of the leaf, or if the construction starts along a single vein it may resemble a

simple irregular tubular tent close to the vein. With further growth of the larvae the retreats first made may be abandoned and others constructed in new feeding areas. Very often when two leaves touch or overlap, the larvae web them together at the point of contact and feed within the webbed area.

After the larvae become more than half grown they migrate from the under to the upper surface of the leaves. Here they spin threads of silk attached to either side of the natural depressions formed by the mid veins, and fold the leaves like the wings of a butterfly. (Figs. 6 and 7.) Very often one edge of the leaf is folded or rolled. The larvae continue to feed until full grown and eventually transform to pupae within these leaf inclosures. If the larvae are disturbed and dislodged from their inclosures new leaves are rolled or folded.

FIGURE 6.—The silk strands spun by the larvae of the strawberry leaf roller on the upper surface of the leaf preparatory to rolling or folding the leaf. × 2

During its entire growth the larva feeds on either the upper or lower surface of a leaf, leaving the epidermis of the opposite surface intact.

## DESCRIPTION OF LARVAL STAGES

The descriptions below and the duration given for the different instars are based on observations of 48 individuals of the second generation.

### First Instar

The first-instar larva measures slightly more than 1.5 mm in length, with the head and thorax much wider than the rest of the body. The head measures 0.18 mm in width, is brown, and the tips of the mandibles are red; the rest of the body is pale green. Many long setae are scattered over the head and from four to six are found on the sides of each thoracic and abdominal segment, those on the anal segment being the longest. The duration of this instar averages 3.8 days.

### Second Instar

After the first molt the larva measures 2.5 mm in length, the head and body being of uniform width. The body color varies somewhat between light green and pale yellow. The setae are arranged as in the first instar. The head across its widest part measures 0.252 mm. The duration of this instar averages 3.4 days.

### Third Instar

After the second molt the larva measures 3.21 mm in length. In appearance it resembles the larva of the previous stage, and very little change in color or other characters is noticeable. The head width is 0.396 mm. The duration of this instar averages 4 days.

### Fourth Instar

After the third molt the larva measures 4.5 mm in length. The body color ranges from yellowish green to dark green. There are four pairs of light hyaline tubercles or prominences on each body segment, two pairs on the dorsal surface, and a pair on each side. The setae are distributed as in the former stages, but are much longer and more prominent. The width of the head is 0.558 mm. The duration of this instar averages 4.8 days.

FIGURE 7.—Strawberry leaves folded or rolled in different ways by the larvae of the strawberry leaf roller. × ¾

### Fifth Instar

After the fourth molt the larva grows rapidly, and when mature measures 12 mm (one-half inch) in length and 1.5 mm in width. (Fig. 1, B.) The general color is gray-brown above and gray beneath, with the head yellowish brown. In other respects it resembles the previous stage. The duration of this instar averages 6.2 days.

### Duration of Larval Period

The duration of the larval period of the two summer generations averaged 24.4 days; that of the last generation, which hibernates, averaged 178.3 days.

### Molts

From a large series of experiments it has been determined that in the spring and summer the larvae ordinarily molt four times. During periods of irregular temperature, in the fall, however, larvae that will hibernate continue to feed when the weather is warm and remain inactive when it is cool. As a result of this prolonged feeding the larvae may undergo several additional molts before cold weather makes them entirely inactive. In regard to larvae kept under obser-

vation during the fall as many as seven molts were observed, though five or six were more common. When mature, these larvae were larger and more robust than those of the summer generation, as is shown by the head widths given in Table 1 for the various instars.

TABLE 1.—*Average head-width measurements of larvae of the strawberry leaf roller*

| Measurement | First instar | Second instar | Third instar | Fourth instar | Fifth instar | Sixth instar |
|---|---|---|---|---|---|---|
| | *Mm* | *Mm* | *Mm* | *Mm* | *Mm* | *Mm* |
| Actual | 0.18 | 0.252 | 0.396 | 0.558 | 0.882 | 1.285 |
| Calculated [a] | .18 | .259 | .372 | .535 | .77 | 1.108 |

[a] Calculations of head widths were made according to Dyar (*2*).

Table 2 shows the average number of days between molts of larvae representing three generations. As would be expected when temperature is a contributing factor, the lengths of instars of the first-generation larvae are somewhat greater than those of the second-generation larvae. The longest interval recorded occurred between the last two molts of the larvae about to hibernate.

TABLE 2.—*Average length of stages and instars in the development of the strawberry leaf roller under laboratory conditions, Riverton, N. J., 1921–22*

| Generation | Egg stage | First instar | Second instar | Third instar | Fourth instar | Fifth instar | Sixth instar | Prepupa | Pupa | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | *Days* | *Days* | *Days* | *Days* | *Days* | *Days* | *Days* | *Days* | *Days* | *Days* |
| First | 15.5 | 3.9 | 3.9 | 4.5 | 6.7 | 7.6 | ..... | 2.5 | 6.8 | 51.4 |
| Second | 7.0 | 3.8 | 3.4 | 4.0 | 4.8 | 6.2 | ..... | 2.5 | 6.2 | 37.9 |
| Third [a] | 7.0 | 3.6 | 3.3 | 3.6 | 4.5 | 8.5 | 12.8 | 142.0 | 12.8 | 198.1 |

[a] Hibernating generation.

### PREPUPAL PERIOD

Upon reaching maturity the larva discharges the waste from the alimentary tract and remains inactive within the folds of the leaf where it has last fed. It may increase the size of its silken retreat after cessation of feeding by spinning a few additional layers of web. The prepupal period in the summer usually lasts from two to three days. The insect hibernates in the prepupal stage, which lasts, on an average, about 142 days. This was determined by observations of the alimentary tract at intervals throughout the dormant period, which showed that no food was taken into the body in the spring prior to pupation.

## THE PUPA

### DESCRIPTION

The pupa (fig. 1, C) averages 8.5 mm in length and is yellowish brown when first formed, becoming dark brown several days before the adult emerges. The dorsal surface of each abdominal segment, with the exception of the last three, bears two transverse rows of spines, those of the anterior row of each segment being stouter than those of the posterior row. Each of the last three segments has a single row of spines. In addition, the last segment bears eight slender hairs which are more or less hooked at the tips.

### DURATION OF PUPAL STAGE

The pupae, as evidenced by their activity, are sensitive to light. They are unable to develop at or above 40° C. or at and below 10° C. In April the duration of the pupal period averaged 12.8 days, in June 6.8 days, and in August 6.2 days. (Fig. 2 shows the temperatures during these months.)

Webster (*11*) states that from meager data the length of this stage in Iowa in April and May was found to be from 14 to 18 days; in the summer months it averaged 6.6 days.

## DURATION OF LIFE CYCLE

Although in breeding experiments under laboratory conditions the average duration of the life cycle of the first generation is 51.4 days and of the second generation 37.9 days (Table 2), it is evident from

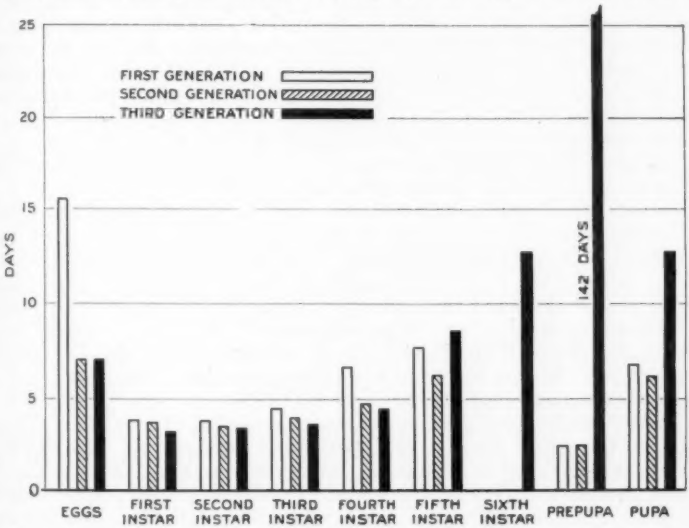


FIGURE 8.—Graph showing the time intervals of the various stages and instars of the three generations of the strawberry leaf roller under laboratory conditions, Riverton, N. J., 1921–22

field observations that the time may be longer if climatic conditions are unfavorable. In such instances temperature and moisture are probably the controlling factors, since food, in the strawberry beds, is nearly always abundant. The generation that includes the hibernating larvae is of course of longer duration, the average length being 198.1 days. (Fig. 8.)

## NUMBER OF GENERATIONS

Insectary breeding experiments show that, when considered from the first eggs laid, the insect had three complete generations and a partial fourth; and when considered from the last eggs laid it had two complete generations and a partial third. Many larvae of the third generation instead of transforming into pupae during August

continued to feed, grow, and molt, and finally passed the winter as full-grown larvae. Other larvae of the same brood transformed into pupae during August, and the moths emerged and deposited eggs. The larvae of this partial fourth generation matured late in the fall and passed the winter successfully. Similar conditions probably occur in the field, and from the finding of larvae of different sizes late in the fall it is supposed that these late-developing larvae came either from the last eggs of the second-brood moths, or from eggs deposited early in the fall by moths of the third generation.

## HIBERNATION

As stated earlier in this discussion, larvae developing in the fall grow much larger than those of the summer generations, and from two to three additional molts occur. It seems evident that this extended period of feeding affords opportunity for the accumulation of a larger amount of adipose tissue, which probably serves the larvae during the period of hibernation. To determine the actual amount of adipose tissue formed, the fat content of the larvae of the summer generations was compared to the fat content of the hibernating larvae. The experimental procedure was as follows: Fifty mature larvae of the summer generations were weighed, macerated, and placed in an oven at 100° C. until the material registered a constant weight. The remains were then extracted several times with equal parts of alcohol and ether and the resulting loss in weight recorded. From these data the percentage of fat was calculated. Similar tests were made with the hibernating larvae. The larvae of the summer generations yielded 3.3 per cent fat, the hibernating larvae 8.7 per cent, or more than double the percentage off at obtained from the summer larvae.

When hibernating larvae were dissected it was noticed that lobed layers of adipose tissue in striking abundance surrounded the alimentary tract. In larvae of the summer generations, however, no such extensive layers of adipose tissue were found.

With the advent of low temperatures in the fall (10° to 15° C.), feeding by the larvae ceases, and the waste products in the digestive tract are entirely eliminated. Numerous examinations made by dissecting hibernating larvae at intervals during the winter months showed that the digestive tract remains practically free of food material, with only a slight accumulation of waste material in the rectum. A reduction of about 15 per cent of the normal (83 per cent) water content takes place previous to hibernation, but to prevent further loss of water and to maintain the minimum consistent with successful hibernation it is necessary that the larvae be constantly surrounded by a humid atmosphere. This condition is maintained in nature by the position of the hibernacula in the moist leaf accumulations on the ground. Experiments demonstrated that hibernating larvae placed in cages indoors would not survive the winter unless proper moisture was supplied. Hibernating larvae placed in a large tin container and kept moist passed the winter without injury.

Throughout the winter months hibernating larvae are only slightly dormant and when subjected to a temperature of 27° C. transform to pupae within from three to six days. That the larvae are extremely resistant to cold is shown by their survival in the colder sections of the country when protected by folded leaves only.

EFFECT OF TEMPERATURE CHANGES ON HIBERNATING LARVAE

For the purpose of determining the influence which a mild or severe winter might have on a spring outbreak of the strawberry leaf roller, a large number of larvae were collected late in the fall, before freezing temperatures occurred. These larvae were divided into five lots and treated according to the following plan: Lot 1 was kept at a temperature of 24° C., and every day 10 individuals were transferred to a temperature of 10°, kept for a certain period, and then placed at a temperature of 24°; lot 2 was kept at a temperature of 31°, and every day 10 individuals were transferred to a temperature of 10°, kept for a certain period, and then placed at a temperature of 24°; lot 3 was treated like lot 2, except that after exposure to a temperature of 10° the larvae were again placed at a temperature of 31°; lot 4 was subjected to a temperature of 10° for a month and then kept at a temperature of 24°; lot 5 was subjected to a temperature of 10° for a month and then held at a temperature of 31°.

In Table 3 the column of figures listed under each temperature represents the number of days 10 larvae were held at that temperature. Under each lot the first temperature is the initial one. For example, under lot 1 the first line means that the 10 larvae were held for 1 day at 24° C., then for 6 days at 10°, and finally for 5 days at 24°, when some larvae pupated. In the same lot the fourth line means that 10 larvae were held at 24° for 3 days and at 10° for 16 days, when some larvae died.

TABLE 3.—*The effect of temperature changes upon hibernating larvae of the strawberry leaf roller*

NUMBER OF DAYS LARVAE WERE EXPOSED AT TEMPERATURES INDICATED (° C.)

| Lot 1 | | | Lot 2 | | | Lot 3 | | | Lot 4 | | Lot 5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24° | 10° | 24° | 31° | 10° | 24° | 31° | 10° | 31° | 10° | 24° | 10° | 31° |
| 1 | 6 | [a]5 | 1 | 6 | [a]5 | 1 | 11 | [a]4 | 30 | [a]3 | 30 | [a]3 |
| 2 | 11 | [a]9 | 2 | 11 | [a]5 | 2 | 13 | [a]5 | 30 | [a]4 | 30 | [a]4 |
| 3 | 15 | [a]15 | 3 | 15 | [a]4 | 3 | 10 | [b]7 | 30 | [a]5 | 30 | [a]5 |
| 3 | [b]16 | ..... | 3 | 16 | [a]4 | 4 | 14 | [b]4 | 30 | [a]6 | 30 | [a]6 |
| 4 | 14 | [b]8 | 4 | 14 | [b]6 | 5 | 12 | [b]3 | 30 | [b]6 | 30 | [a]7 |
| 5 | 15 | [b]5 | 4 | [b]14 | ..... | 6 | 13 | [b]4 | 30 | [b]8 | 30 | [b]6 |
| 5 | 16 | [b]3 | 5 | 13 | [b]2 | 7 | [b]15 | ..... | 30 | [a]8 | 30 | [a]8 |
| 8 | [b]19 | ..... | 5 | 13 | [b]8 | 8 | 16 | [b]2 | 30 | [a]12 | 30 | [a]9 |
| 9 | 18 | [b]5 | 6 | [b]13 | ..... | 9 | 19 | [b]5 | ..... | ..... | ..... | ..... |
| 10 | [b]18 | ..... | 6 | 16 | [b]8 | 10 | 17 | [b]4 | ..... | ..... | ..... | ..... |
| 10 | [b]23 | ..... | 7 | 15 | [b]3 | 11 | 18 | [b]5 | ..... | ..... | ..... | ..... |
| 13 | [b]28 | ..... | 7 | [b]16 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 14 | [b]27 | ..... | 10 | [b]23 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 16 | [b]6 | ..... | 11 | [b]25 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 17 | [b]5 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 19 | [b]3 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |

[a] Some larvae pupated. [b] Some larvae died.

The results indicate quite clearly that with slight exceptions the mortality was greatest in those larvae activated by a high temperature before they were subjected to a low temperature. This is strikingly revealed in the results obtained from lots 1, 2, and 3, which suffered a mortality of over 90 per cent. In contrast to the above, the larvae of lot 4 were not subjected to a high temperature, and consequently were not rendered active, before exposure to a low temperature. When these larvae were exposed to a high temperature, development continued normally, and they pupated later with a death rate

of only 6 per cent. An exposure of less than four days to a temperature of 31° C. was apparently not of sufficient duration to activate the larvae, and when they were later subjected to a temperature of 10° no injury resulted. On the other hand, when larvae were subjected to a temperature of 31° for four days or more, activation and probably development progressed sufficiently to cause injury and death when they were exposed to a temperature of 10°, but a sudden shift from 10° to 25° or 30° was not fatal, provided there was no further exposure to temperatures below 10°.

From the results here recorded it appears that there is perhaps a particular stage in the development of the larvae at which hibernation may be successful, possibly a stage in which the concentration of certain ingredients permits the protoplasm to resist a low temperature. It is evident, therefore, that a sustained high temperature in the field for a sufficient length of time during the winter followed by a temperature of 10° C. or lower would be sufficient to cause a high rate of mortality and preclude the possibility of an outbreak of this pest.

When hibernating larvae become activated at a temperature of 24° C. for a sufficient length of time to cause development to proceed toward pupation, the resulting pupae were found to resist a temperature of 10° for only a short interval. This was shown by the following observation: During examinations made when the temperature was 10° some pupae which had previously been exposed to a temperature of 24° were observed to have proceeded in their development to a point represented by a dark-brown coloration. Under normal conditions moths would have appeared several days later, but further development was checked and death of the pupae followed. Other pupae of the same lot similarly treated made no progress in development and died in the early part of pupal life.

### EFFECT OF TEMPERATURE ON PUPAL DEVELOPMENT

The rate of development of the pupa was found to be greatly dependent, within certain limits, upon temperature conditions, as shown by the following experiments: Recently formed pupae were divided into six lots and when treated as shown completed development in the number of days specified—

Lot 1. Pupae held at a constant temperature of 20° C. completed development in 12 days.
Lot 2. Pupae held at a constant temperature of 24° completed development in 12 days.
Lot 3. Pupae held at a constant temperature of 27° completed development in 5.5 days.
Lot 4. Pupae held at a constant temperature of 34° completed development in 4 days.
Lot 5. Pupae held at a constant temperature of 40° died.
Lot 6. Pupae held at a constant temperature of 10° died.

From these data it is apparent that the limits of development for the pupae probably lie between 15° and 34° C., with an optimum between 27° and 34°.

## NATURAL CONTROL

### PARASITES

It would appear from the large number of parasites reared from the larval and pupal stages of the strawberry leaf roller that it is ordinarily held in check by natural enemies. In the vicinity of Riverton,

N. J., more than a dozen species of parasites were reared. A few proved to be new to science, and several species were observed to be of considerable economic importance in the natural control of the strawberry leaf roller. They are listed below in the order of their probable importance: *Macrocentrus ancylivora* Roh., *Cremastus cookii* Davis, *Spilocryptus exannulatus* Cush., *Exorista pyste* Walk., *Perisierola* sp.,

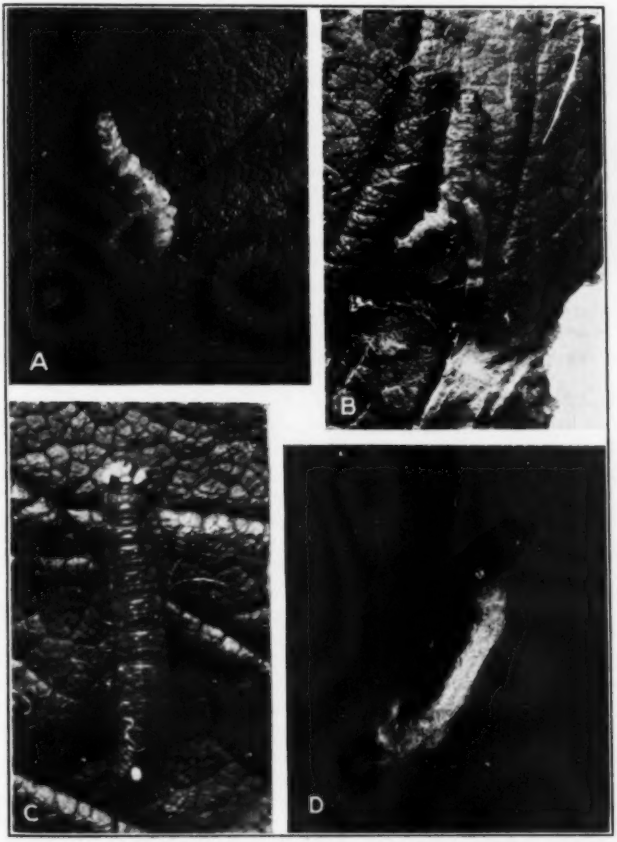


FIGURE 9.—Parasites of the strawberry leaf roller: A, larva of *Macrocentrus ancylivora* emerging from a leaf-roller larva; B, three larvae of a species of Perisierola feeding on a larva of the strawberry leaf roller; C, strawberry leaf-roller larva bearing eggs of *Exorista pyste;* D, cocoon of *Spilocryptus exannulatus* constructed after emergence from a pupa of the strawberry leaf roller. All × 4

*Sympiesis ancylae* Gir., *Dibrachys meteori* Gahan, *D. aeneoviridis* Gir., *Habrocytus* sp., *Pseudacrias* (*Pleurotropis*) *sexdentatus* Gir., *Spilochalcis* sp., *Epiurus indagator* Walsh, *Itoplectis conquisitor* Say.

*Macrocentrus ancylivora* (fig. 9, A) is considered one of the most important of the parasites, since 60 per cent of the larvae of the strawberry leaf roller collected during June and August were found parasitized by this species. It is a large yellow braconid, the body of the

female measuring 4.5 mm in length and having an ovipositor 5.5 mm in length. The male is somewhat smaller, measuring 3.5 mm in length. The biology of this parasite has been described by the writer (*4*).

*Cremastus cookii* parasitized 15 per cent of the larvae of the strawberry leaf roller collected during June and August. This species is slightly larger than *Macrocentrus ancylivora*, measuring from 6 to 7 mm in length and having an ovipositor about two-thirds the length of the abdomen. Although no studies of its biology were made, observations indicate that its habit of parasitizing the host resembles that of *M. ancylivora*.

*Spilocryptus exannulatus* parasitized from 5 to 10 per cent of the larvae of the strawberry leaf roller collected during June and August. The egg of this parasite is deposited within the larva of the host. The latter, however, is able to develop and pupate, although the parasite larva eventually consumes the contents of the pupa. It then emerges from the pupal remains of the host as a larva and spins about itself a white cocoon. (Fig. 9, D.) The pupal stage lasts from 10 to 14 days. The adult measures 5.5 mm in length, but its ovipositor is only 1.5 mm long. The thorax and posterior part of the abdomen are black, and the anterior portion of the abdomen is yellowish brown.

A species of Perisierola (family Bethylidae) parasitized only from 2 to 5 per cent of the strawberry leaf-roller larvae collected during June. The adult deposits several eggs on the abdomen of the host larva, and the parasitic larvae that hatch from these eggs insert their mouth parts through the epidermis and feed from the exterior upon the internal contents of the host. (Fig. 9, B.) After two or three days the parasitic larvae attain full growth and, without constructing a cocoon about themselves, fasten their anal segments by means of threads of silk to the leaf and transform to pupae in their larval skins, which eventually become jet black. The pupal stage lasts from five to eight days.

The tachinid fly *Exorista pyste* parasitized 5 per cent of the larvae of the host. The adult fly deposits from one to three eggs, either on the thorax or on the last abdominal segment of the host. (Fig. 9, C.) The white, glossy, hemispherical eggs measure 0.456 by 0.27 mm, and their surfaces are reticulated. The lower flattened surface adheres tenaciously to the skin of the host. In hatching, the eggshell splits at one side close to the base, and the parasitic larva bores through the skin into the interior of the host. The host larva, however, is able to mature and transform into the pupal stage, and the parasitic larva, after consuming the contents of the pupa, emerges by breaking through the pupal skin of the host. In many instances the puparium of the parasite was found partly within the empty pupal skin, indicating that pupation had occurred without the parasitic larva entirely emerging from the host. The puparium measures 4 by 1.7 mm and is dark brown. The pupal stage lasts from a week to 10 days. If the host larva bearing eggs of this parasite happens also to be parasitized by *Macrocentrus ancylivora* only the latter develops.

### PREDACIOUS ENEMIES

The strawberry leaf roller is also attacked by several species of predacious insects. The bugs *Nabis ferus* L. and *Podisus maculiventris* Say and the beetle *Casnonia pennsylvanica* L. were observed feeding on the larvae.

## SUMMARY

The strawberry leaf roller feeds on the foliage of the strawberry, blackberry, and raspberry and may become established in widely separated localities through the transportation and setting out of infested plants.

Fertilized females deposit from 20 to 120 eggs, usually on the under surface of the leaves, and the eggs hatch in from 5 to 17 days.

Until half grown the young larvae feed on the under surface of the leaves protected by silky retreats. They then migrate to the upper surface of the leaves, which they roll or fold, and within these folded leaves they continue feeding and finally pupate. The summer-generation larvae molt four times, and the hibernating larvae may molt six or more times.

The prepupal period in the summer generations lasts from two to three days and in the hibernating generation it lasts throughout the winter. The pupal stage lasts from 6 to 13 days. The life cycle, or developmental period, of the summer generations averaged 51.4 days for the first generation and 37.9 days for the second, and that of the hibernating generation averaged 198.1 days.

Hibernation takes place in the prepupal stage within the rolled or folded strawberry leaves lying on the surface of the ground. An increase in the accumulation of adipose tissue and a reduction of the water content of these larvae precede hibernation.

Experiments indicate that when hibernating larvae are subjected to a temperature of 24° or 31° C. for four days or more and are afterwards placed at a temperature of 10° for a considerable time a high mortality results. If kept first at a temperature of 10° for a considerable length of time and afterwards placed at a temperature of 24° or 31°, pupation occurs and the mortality is very low.

Experiments with pupae indicate that the limits of pupal development are between 15° and 34° C., with an optimum between 27° and 34°.

The strawberry leaf roller is attacked by more than a dozen species of parasites of which the following are the most important: *Macrocentrus ancylivora*, *Cremastus cookii*, *Spilocryptus exannulatus*, and *Exorista pyste*.


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# EFFECTS ON COTTON OF IRREGULAR DISTRIBUTION OF FERTILIZERS[1]

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## INTRODUCTION

In 1929 the joint committee on fertilizer application,[3] the South Carolina Agricultural Experiment Station, and the United States Department of Agriculture joined forces to study the efficiency of fertilizer distributors designed for use in growing cotton. The field tests were conducted at two locations in South Carolina.

A previous paper[4] gives the specifications of the 22 distributors selected for this work, the formulas of the fertilizers used, details of the experiment, and observations obtained in the field and laboratory. The field observations included measurements of the effects of the fertilizers on germination, earliness of blooming, rate of growth, and yield. These results were presented from the standpoint of the efficiency of the distributors.

Earlier studies[5 6] have shown that distributors apply fertilizers unevenly along the row, owing to cycles of delivery and other causes. They differ widely, however, in the kind and extent of these variations in delivery, as may be seen in Figure 1. It would be reasonable to suppose that such differences in distribution would produce corresponding effects on the crop, but insufficient evidence is available to show the character or magnitude of these effects.

The present paper gives a statistical analysis of some of the results previously published, in order to show the differences in the effects of fertilizers on cotton when applied uniformly and with typical degrees of irregularity.

## PLANTING

The results of the applications made by hand and by distributors Nos. 1, 2, 4, 5, and 8 in the previous study[7] were selected for this work, because the conditions surrounding them were substantially the same for each test, except that the fertilizers were applied with different degrees of variability of distribution. The fertilizers were applied in open furrows, over which raised seed beds were formed and dragged to a uniform height. Later examination of the placements showed that the fertilizers were in bands 2 or 3 inches wide and 3 inches below the surface. The seeds were planted 1 inch below the surface at the rate of 1 every inch. Thus in each instance the fertilizer was placed in narrow bands 2 inches below the seed.

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[1] Received for publication Nov. 13, 1931; issued May, 1932.

[2] Credit is due Avis J. Peterson, Fertilizer and Fixed Nitrogen Investigations, Bureau of Chemistry and Soils, for a large number of the calculations required in this work.

[3] Composed of representatives of the American Society of Agronomy, the American Society of Agricultural Engineers, the National Association of Farm Equipment Manufacturers, and the National Fertilizer Association.

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A coefficient of variability ($V$) may be used as a measure of the degree of irregularity of distribution of the fertilizer. It is calculated from the weights of material in consecutive parts of the row. $V$ was calculated for each machine from the weights of fertilizer delivered in 40 consecutive 1-foot sections of row, and the values obtained cover the usual range in practice. Special precautions were used in making the hand applications, and, although strictly speaking they could not be perfect, they may be considered uniform ($V=0$). These determined values of $V$ will be used hereafter to designate the different degrees of variability of distribution.

Eight plantings, each consisting of a set of the several degrees of variability of distribution of the fertilizers, were made at intervals during a period of seven weeks. The first six were made at the Sand-

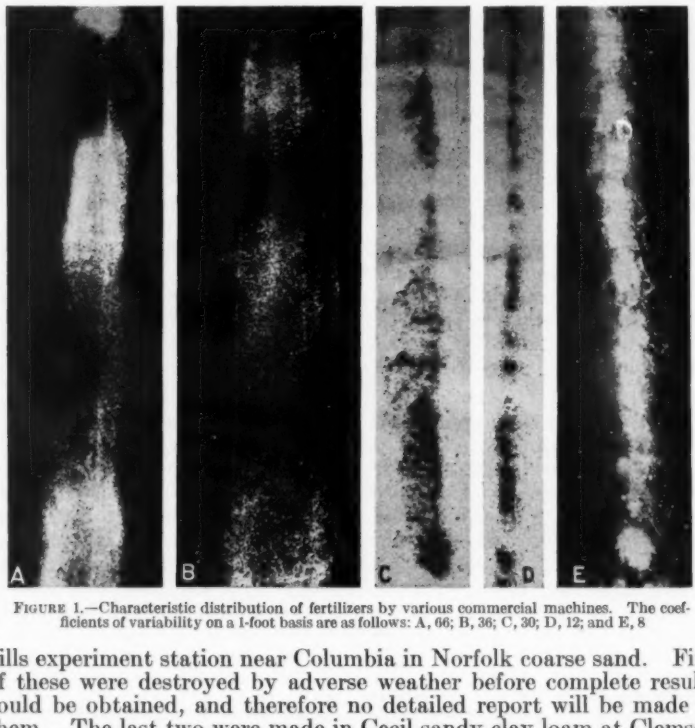


FIGURE 1.—Characteristic distribution of fertilizers by various commercial machines. The coefficients of variability on a 1-foot basis are as follows: A, 66; B, 36; C, 30; D, 12; and E, 8

hills experiment station near Columbia in Norfolk coarse sand. Five of these were destroyed by adverse weather before complete results could be obtained, and therefore no detailed report will be made of them. The last two were made in Cecil sandy clay loam at Clemson College. Each test consisted of four replicate plots in different parts of the field. The plots were single 36-foot rows staked out of the middle of longer rows.

The rates of application of the 4–8–4 and 12–24–12 fertilizers were as close to 800 and 267 pounds per acre, respectively, as the various machines were capable of giving. The rates actually obtained were determined in each test and are shown in Table 1. The rates were such that the same amounts of nitrogen, phosphoric acid, and potash were applied in each fertilizer.

TABLE 1.—*The number of cotton plants per 36-foot row above ground on the dates shown for different degrees of variability of distribution of 4–8–4 and 12–24–12 fertilizers applied at the rates indicated*

| Kind of fertilizer | Method of application | V* | Quantity of fertilizer applied and number of plants standing in— | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Norfolk coarse sand, planting No. 6, planted May 9 | | | | Cecil sandy clay loam, planting No. 7, planted May 14 | | | | Cecil sandy clay loam, planting No. 8, planted May 24 | | | |
| | | | Fertilizer applied | Plants standing on— | | | Fertilizer applied | Plants standing on— | | | Fertilizer applied | Plants standing on— | | |
| | | | | May 22 | May 29 | June 11 | | May 21 | May 31 | June 6 | | May 31 | June 7 | June 12 |
| | | | *Pounds per acre* | *Number* | *Number* | *Number* | *Pounds per acre* | *Number* | *Number* | *Number* | *Pounds per acre* | *Number* | *Number* | *Number* |
| 4–8–4 | Hand | 0 | 800 | 41±15 | 343± 6 | 311±10 | 800 | 306±8 | 289± 5 | 287± 2 | 800 | 272± 4 | 365± 3 | 332± 4 |
| | Distributor No. 1 | 8 | 794 | 64± 7 | 358± 6 | 332± 8 | 636 | 311±6 | 315± 3 | 306± 5 | 683 | 313±15 | 419± 7 | 419± 6 |
| | Distributor No. 4 | 9 | 752 | 35± 7 | 366± 4 | 333± 6 | 962 | 305±5 | 310± 1 | 315± 1 | 727 | 275± 3 | 394± 8 | 401± 7 |
| | Distributor No. 5 | 10 | 821 | 103±14 | 334± 5 | 301± 8 | 836 | 309±7 | 295± 1 | 298± 1 | 708 | 278± 8 | 413± 9 | 491±10 |
| | Distributor No. 8 | 15 | 735 | 99±24 | 355±10 | 338±12 | 750 | 321±7 | 321± 2 | 331± 4 | 727 | 271± 7 | 370± 9 | 372± 9 |
| | Distributor No. 2 | 56 | 767 | 123±24 | 354± 7 | 334± 8 | 800 | 316±6 | 342± 4 | 319± 3 | 692 | 272± 9 | 396±12 | 402±13 |
| None | | | | 242± 7 | 366± 4 | 335± 5 | | 311±6 | 305± 1 | 312± 5 | | 270± 8 | 420± 7 | 415± 9 |
| 12–24–12 | Hand | 0 | 267 | 71±21 | 279±23 | 257±27 | 267 | 315±5 | 296±13 | 325±11 | 267 | 277± 1 | 374± 4 | 367±15 |
| | Distributor No. 4 | 18 | 305 | 59±14 | 273±21 | 241±28 | 255 | 305±8 | 307±10 | 327±10 | 304 | 277±15 | 377±16 | 379±18 |
| | Distributor No. 1 | 20 | 307 | 148±10 | 302±11 | 273±12 | 303 | 320±6 | 324± 6 | 345± 3 | 287 | 289±10 | 383± 4 | 376± 4 |
| | Distributor No. 5 | 24 | 320 | 176±16 | 288± 8 | 260± 8 | 391 | 298±7 | 317± 5 | 335± 8 | 355 | 249±16 | 378±10 | 375±10 |
| | Distributor No. 8 | 31 | 227 | 155±23 | 301±14 | 279±16 | 205 | 315±6 | 297± 9 | 327±11 | 236 | 218± 8 | 356± 4 | 343± 1 |
| | Distributor No. 2 | 66 | 250 | 181±21 | 322±12 | 285±12 | 249 | 322±4 | 308±13 | 319± 5 | 230 | 274±12 | 398±14 | 397±11 |
| None | | | | 257±14 | 361± 4 | 340± 1 | | 314±3 | 340± 9 | 341± 5 | | 280±10 | 399± 9 | 383± 3 |

* Variability of distribution based on 1-foot intervals of delivery.

The same machines applied both fertilizers, but from the values of $V$ it will be seen that the degree of variability was greater in each case when the smaller quantity of the concentrated fertilizer was applied by the same machine.

With the greatest degree of irregularity, the fertilizer was deposited in the manner shown at A in Figure 1, and the high points in the delivery cycle were about 17 feet apart where roughly ten times as much fertilizer was deposited as at the low points. With the smallest degree they were 3.8 feet apart, and the delivery rate varied from 20.6 to 28.6 g per foot.

## GERMINATION

### NUMBER OF SEED GERMINATING

The sixth planting was made on May 9, and at this time the coarse sand contained 5.3 per cent moisture. From May 17 until the middle of June rains fell every few days. Consequently the soil moisture was favorable during most of the germination period. The fertilizers slightly delayed germination on this soil, as shown by the results of counts in Table 1. Pearson's correlation coefficient, $r$, between the numbers of seedlings aboveground at the first count and the corresponding coefficients of variability is $0.734 \pm 0.089$. There was a definite tendency, therefore, for more seed to germinate promptly where the fertilizer was irregularly applied. At the last count there were no significant differences in the number of seedlings due to irregular distribution. The percentage of germination was lower on all the plots fertilized with the 12–24–12 mixture in this planting.

Plantings Nos. 7 and 8 were made on Cecil sandy clay loam containing 15.47 per cent moisture on May 14 and 11.6 per cent on May 24. A rain amounting to 0.81 inch fell on May 27, but during the remainder of the germination period the rainfall was very slight. There was no significant delay in germination on this soil, and the percentage of germination was the same with both fertilizers.

The results of other experiments on these soils where the same amounts of fertilizer were placed 2 inches below the seed, although not given here, also indicate that in light sandy soils the percentage germination is likely to be somewhat lower when fertilizers are uniformly distributed than when irregularly distributed, but on heavy clay soils no significant differences occur as a rule.

### SPACING OF THE SEEDLINGS

Plants appeared simultaneously all along the rows on the uniformly fertilized plots, but they came up in bunches at the low points in delivery on the Norfolk sand plots that were fertilized in a cyclic manner. Figure 2 shows irregular germination due to the same cause in a later experiment on Ruston sandy loam. Although the total number of seedlings finally appearing above ground in any one group of tests was approximately the same for each degree of variability of distribution, the seedlings were more uniformly distributed along the row on the uniformly fertilized plots. These plots had at least one seedling in each foot of row, and in a few cases as many as 3 consecutive feet were bare on plots where $V = 56$ and 66. The last count for each planting was made after new seedlings ceased to appear, and the number of plants in each foot of row was counted separately.

Standard deviations ($\sigma$) of the number of plants per foot of row were calculated, therefore, to determine the effect of each degree of variability on uniformity of stand. Each value of $\sigma$, presented in Table 2, is based on 144 feet of row.

TABLE 2.—*Standard deviations ($\sigma$) of the numbers of cotton plants per foot of row for different degrees of variability of distribution ($V$) of fertilizers*

| Kind of fertilizer | $V$ | Standard deviations of numbers of plants per foot of row standing in— | | | | | | Averages of the differences from the checks for the three tests |
|---|---|---|---|---|---|---|---|---|
| | | Norfolk coarse sand, planting No. 6 | | Cecil sandy clay loam, planting No. 7 | | Cecil sandy clay loam, planting No. 8 | | |
| | | $\sigma$ | Differences from checks | $\sigma$ | Differences from checks | $\sigma$ | Differences from checks | |
| 4-8-4 | 0 | 2.09±0.08 | +0.05 | 2.80±0.15 | +0.03 | 3.88±0.15 | +0.37 | +0.15 |
| | 8 | 1.85± .07 | −.19 | 3.15± .12 | +.38 | 3.62± .04 | +.11 | +.10 |
| | 9 | 2.29± .09 | +.25 | 3.02± .17 | +.25 | 3.59± .16 | +.08 | +.19 |
| | 10 | 2.10± .08 | +.06 | 2.91± .31 | +.14 | 3.76± .17 | +.25 | +.15 |
| | 15 | 2.30± .09 | +.26 | 3.03± .26 | +.26 | 3.98± .16 | +.47 | +.33 |
| | 56 | 2.63+ .10 | +.59 | 3.44+ .27 | +.67 | 4.10± .03 | +.59 | +.62 |
| None | | 2.04± .08 | | 2.77± .18 | | 3.51± .10 | | |
| 12-24-12 | 0 | 2.38± .09 | +.24 | 1.82± .16 | −.09 | 3.12± .11 | −.21 | −.02 |
| | 18 | 2.48± .10 | +.34 | 2.09± .15 | +.18 | 3.58± .38 | +.25 | +.26 |
| | 20 | 2.60± .10 | +.46 | 2.28± .27 | +.37 | 3.86± .15 | +.53 | +.45 |
| | 24 | 2.83± .11 | +.69 | 2.34± .05 | +.43 | 3.70± .13 | +.37 | +.50 |
| | 31 | 2.78± .11 | +.64 | 2.56± .29 | +.65 | 3.72± .21 | +.39 | +.56 |
| | 66 | 2.83± .11 | +.69 | 2.74± .29 | +.83 | 4.08± .11 | +.75 | +.76 |
| None | | 2.14± .09 | | 1.91± .20 | | 3.33± .19 | | |

FIGURE 2.—Irregular stand of cotton due to irregular distribution of 4-8-4 fertilizer applied at a rate of 800 pounds per acre in a 2-inch band 2 inches below the seed. The spacing of the bunches of plants in the foreground corresponds closely to the length of the delivery cycle (5.4 feet). The correspondence, however, in other plots was not so close as that shown here

A certain amount of irregularity of spacing is due to irregular planting of the seed, which varied somewhat from an average of about 12 seed per foot. This variation was greatest in plantings Nos. 7 and 8. Part of the irregularity of stand was also due to differences in soil and viability of the seed. We may assume that all such effects on stand will be measured approximately by the value of $\sigma$ for the unfertilized checks. These causes should have had about the same effects

on each $\sigma$ for the same group, but if the fertilizer at certain points prevented seeds from germinating, the corresponding value of $\sigma$ will be higher. Consequently the differences between the values of $\sigma$ for the fertilized and corresponding check plots are an indication of the effect of the irregular distribution of the fertilizer on stand. Irregular distribution of the fertilizer increased the value of $\sigma$ by a maximum of about 0.8. This of course means that a number of seed were prevented from germinating at several points in each plot where excessive amounts of fertilizer were deposited. When the differences between $\sigma$ for the fertilized and unfertilized plots are averaged for the three plantings, as shown in the last column of Table 2, and correlated with the corresponding values of $V$, $r$ equals $0.920 \pm 0.030$.

Thus, although irregular distribution had no marked effect on the percentage of germination in these tests, it did have a measurable effect on the uniformity of spacing of the plants, and the effect was proportional to the degree of variability of distribution. Fertilizers when uniformly applied had no very significant effect on either percentage of germination or uniformity of stand.

## EARLY GROWTH AND BLOOM

After the plants were well started a tapeline was laid beside the rows, and the plants were thinned by hand wherever possible to a stand of one plant every 6 inches. The height of a dozen plants from each plot was measured at this time. The heights given in Table 3 were obtained by averaging the mean figures from the four replicates.

TABLE 3.—*Average heights of cotton plants as an indication of rate of growth for different degrees of variability of distribution (V) of fertilizers*

| Fertilizer and rate of application per acre | $V$ | Average heights of plants (inches) standing in— | | | | | |
|---|---|---|---|---|---|---|---|
| | | Norfolk coarse sand, planting No. 6 | | Cecil sandy clay loam, planting No. 7 | | Cecil sandy clay loam, planting No. 8 | |
| | | June 11 | July 9 | June 15 | July 3 | June 15 | July 3 |
| 800 pounds, 4–8–4[a] | 0 | 7.4 | 13.1 | 12.2 | 17.8 | 7.4 | 15.1 |
| | 8 | 7.1 | 12.3 | 10.7 | 16.8 | 7.3 | 12.7 |
| | 9 | 7.3 | 10.8 | 10.7 | 15.0 | 7.2 | 12.3 |
| | 10 | 6.8 | 12.6 | 10.8 | 14.6 | 7.7 | 11.5 |
| | 15 | 7.0 | 12.6 | 9.9 | 14.4 | 7.4 | 11.6 |
| | 56 | 6.8 | 11.2 | 9.3 | 15.4 | 7.4 | 11.6 |
| None | | 4.5 | 7.5 | 7.1 | 11.5 | 6.0 | 10.1 |
| 267 pounds 12–24–12[a] | 0 | 7.2 | 14.6 | 11.0 | 15.9 | 7.1 | 11.1 |
| | 18 | 6.6 | 12.6 | 8.9 | 13.6 | 7.3 | 11.5 |
| | 20 | 6.6 | 9.6 | 9.1 | 13.7 | 6.9 | 12.5 |
| | 24 | 5.8 | 10.5 | 9.5 | 15.2 | 7.3 | 12.5 |
| | 31 | 6.1 | 10.9 | 9.2 | 14.8 | 7.4 | 11.8 |
| | 66 | 6.5 | 10.2 | 9.2 | 14.1 | 6.9 | 12.5 |
| None | | 4.5 | 7.4 | 7.4 | 11.1 | 6.3 | 10.2 |
| Mean probable errors of heights | | ±.18 | ±.37 | ±.17 | ±.32 | ±.10 | ±.32 |
| $r$ between $V$ and heights of plants | | −.501 | −.612 | −.685 | −.413 | −.285 | −.182 |
| Probable errors of $r$ | | ±.146 | ±.122 | ±.103 | ±.161 | ±.179 | ±.188 |

[a] Approximately; for exact rates see Table 1.

A rather definite correlation is shown between $V$ and the average rate of growth by the values of $r$ at the bottom of Table 3. In general the uniformly fertilized plants grew more rapidly than the unevenly

fertilized ones, and they also varied less in size, as will be seen by comparing Figures 3 and 4.

The results of bloom counts are given in Table 4. Although some of the figures are erratic, uniform distribution of fertilizer appears to be of real value in promoting early blooming.

FIGURE 3.—A, Unfertilized cotton plants used as checks; B, uniformly fertilized plants

TABLE 4.—*Number of cotton-plant blooms per plot as related to various degrees of variability of distribution (V) of fertilizers*

| Fertilizer and rate of application per acre | V | Number of blooms per plot on plants standing in— | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Norfolk coarse sand, planting No. 6 | | | | Cecil sandy clay loam, planting No. 7 | | | | Cecil sandy clay loam, planting No. 8 | | | |
| | | July 18–24 | July 25–31 | Aug. 1–3 | Total | July 26–Aug. 1 | Aug. 2–8 | Aug. 9–10 | Total | July 26–Aug. 1 | Aug. 2–8 | Aug. 9–10 | Total |
| 800 pounds 4–8–4[a] | 0 | 14 | 60 | 27 | 101 | 53 | 122 | 60 | 235 | 43 | 115 | 64 | 222 |
| | 8 | 5 | 54 | 28 | 87 | 50 | 81 | 41 | 172 | 38 | 95 | 57 | 190 |
| | 9 | 4 | 46 | 24 | 74 | 47 | 105 | 35 | 187 | 40 | 103 | 53 | 196 |
| | 10 | 8 | 61 | 26 | 95 | 45 | 93 | 50 | 188 | 27 | 83 | 45 | 155 |
| | 15 | 8 | 60 | 26 | 94 | 48 | 102 | 46 | 196 | 23 | 105 | 54 | 182 |
| | 56 | 8 | 56 | 33 | 97 | 52 | 88 | 46 | 186 | 28 | 100 | 52 | 180 |
| None | | 0 | 0 | 1 | 1 | 13 | 59 | 34 | 106 | 4 | 25 | 13 | 42 |
| 267 pounds 12–24–12[a] | 0 | 6 | 40 | 19 | 65 | 50 | 84 | 63 | 197 | 23 | 105 | 28 | 156 |
| | 18 | 4 | 41 | 21 | 66 | 43 | 92 | 45 | 180 | 20 | 92 | 34 | 146 |
| | 20 | 5 | 31 | 15 | 51 | 38 | 96 | 50 | 184 | 22 | 83 | 27 | 132 |
| | 24 | 3 | 45 | 19 | 67 | 41 | 96 | 53 | 190 | 16 | 70 | 27 | 113 |
| | 31 | 4 | 50 | 18 | 72 | 24 | 87 | 32 | 143 | 4 | 29 | 14 | 47 |
| | 66 | 3 | 26 | 12 | 41 | 32 | 99 | 50 | 181 | 13 | 66 | 26 | 105 |
| None | | 0 | 0 | 1 | 1 | 15 | 48 | 31 | 94 | 2 | 22 | 7 | 31 |

[a] Approximately. For exact rates see Table 1.

## YIELDS

The crops were harvested in two pickings, and the weights of seed cotton converted to an acre basis are presented in Table 5.

TABLE 5.—*Yields of seed cotton (pounds per acre) when fertilizers were applied with various degrees of variability of distribution (V)*

| Kind of fertilizer | V, corrected to uniform rate of application | Quantity of seed cotton (pounds per acre) yielded by plants standing in— | | | | | | | | | Means of total yields of three plantings | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Norfolk coarse sand, planting No. 6 | | | Cecil sandy clay loam, planting No. 7 | | | Cecil sandy clay loam, planting No. 8 | | | | |
| | | First picking Oct. 10 [a] | Total | Total corrected to uniform rate of fertilization | First picking Oct. 14 [b] | Total | Total corrected to uniform rate of fertilization | First picking Oct. 15 [b] | Total | Total corrected to uniform rate of fertilization | Crude data | Corrected to uniform rate of fertilization |
| 4-8-4 | 0 | 832±63 | 861±65 | 861 | 940± 1 | 993± 1 | 993 | 1,047± 1 | 1,255±21 | 1,255 | 1,036 | 1,036 |
| | 7.8 | 781±26 | 821±23 | 825 | 773±23 | 884±15 | 921 | 865±21 | 1,070±11 | 1,118 | 925 | 955 |
| | 9.3 | 670±58 | 736±50 | 758 | 914±24 | 1,003±29 | 960 | 875±20 | 1,093±12 | 1,120 | 944 | 946 |
| | 9.6 | 735±23 | 794±24 | 786 | 841±38 | 986±55 | 976 | 833±30 | 1,102±32 | 1,138 | 961 | 967 |
| | 15.1 | 623±23 | 662±21 | 695 | 846±35 | 940±33 | 952 | 862±41 | 1,137±37 | 1,160 | 913 | 936 |
| | 55.3 | 660±52 | 698±51 | 710 | 763±18 | 872±13 | 872 | 805±17 | 967±14 | 1,002 | 846 | 861 |
| None | | 30± 5 | 65± 7 | | 493±19 | 594±24 | | 247±18 | 495±27 | | 385 | |
| 12-24-12 | 0 | 640±64 | 681±62 | 681 | 1,074±19 | 1,265±40 | 1,265 | 866±21 | 1,093± 6 | 1,093 | 1,013 | 1,013 |
| | 18.0 | 488±42 | 533±43 | 501 | 890±18 | 1,061±27 | 1,076 | 740±51 | 976±32 | 940 | 857 | 839 |
| | 19.7 | 540±83 | 587±88 | 545 | 1,077±38 | 1,256±46 | 1,210 | 685±17 | 943±27 | 925 | 929 | 893 |
| | 24.0 | 437±74 | 437±74 | 420 | 907±67 | 1,107±81 | 1,052 | 598±31 | 882±35 | 850 | 809 | 774 |
| | 30.6 | 415±40 | 415±40 | 446 | 726±39 | 889±59 | 961 | 585±54 | 840±67 | 868 | 715 | 758 |
| | 66.2 | 356±41 | 404±40 | 414 | 929±42 | 1,071±47 | 1,080 | 475±58 | 674±46 | 706 | 716 | 733 |
| None | | 32± 7 | 64±12 | | 508±33 | 681±36 | | 92± 9 | 297±41 | | 347 | |

[a] Second picking, Nov. 8.

[b] Second picking, Nov. 6.

As stated previously, every effort was made to distribute the ordinary and concentrated fertilizers at rates of 800 and 267 pounds per acre, respectively, and the rates actually obtained are given in Table 1. These rates, as well as those used in determining the coefficients of variability of distribution, were sufficiently different from the standards in some cases to influence the yields. It was therefore desirable, if possible, to correct both sets of figures for these discrepancies.

The South Carolina experiment station[8] had been studying the effect of varying the rate of application of 4–8–4 fertilizers on the yields of cotton for a number of years, under conditions very similar to those of the present experiments. These data were used in an attempt to correct the present yields in the following manner: Two curves, which may be called the master curves, were drawn to represent the relationship shown by the experimental evidence between rate of application and yields. The yield to be corrected and its corresponding check yield were then plotted on the same chart with its master curve, and a smooth curve of the same shape as the master curve was drawn through

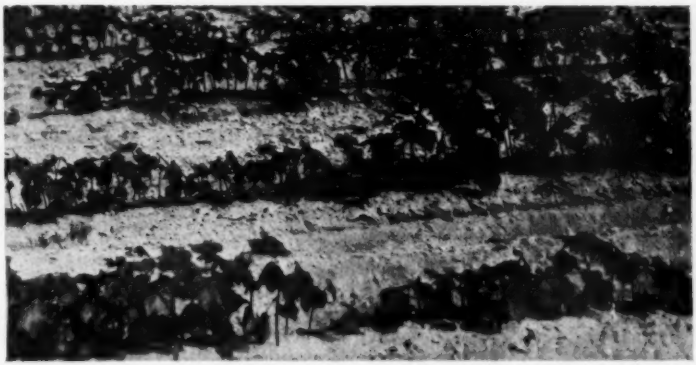

FIGURE 4.—Irregularly fertilized cotton plants. Groups of tall plants occur at intervals approximately corresponding in length to those of the cycles of delivery of the 4-8-4 fertilizer ($V$=55)

the two points. The corrected yields (shown in Table 5) were determined by the points at which these curves crossed the 267 and 800 pounds per acre lines in the graph.

The hand distribution was assumed to have a coefficient of variability of zero, as was explained previously. In all other cases $V$ could be corrected because it had been determined for each machine at two or more rates of application. The coefficients obtained in each case were plotted against rate of application and the several points were connected by a smooth curve. Corrected coefficients of variability were read from these curves and are also given in Table 5. It will be noticed that the check yields are the same for both fertilizers in planting No. 6 but are different in plantings Nos. 7 and 8. This is probably because Nos. 7 and 8 were located on terraced land, which is characteristic of this section of the Cotton Belt. In the seventh planting the 12–24–12 group of tests was on the lower part of a terrace,

[8] BUIE, T. S., and WARNER, J. D. COTTON FERTILIZER EXPERIMENTS. S. C. Agr. Expt. Sta. Bul. 245, 32 p., illus. 1928.

and the 4–8–4 group was on the higher part of the slope. In the eighth planting these conditions were reversed. The growing conditions on the lower part of such terraces are probably somewhat different from those on the upper.

The uniformly applied fertilizer is clearly superior to that where $V=7.8$ or 18, and these in turn are decidedly superior to the most irregularly applied fertilizer in increasing yields. The differences in the six cases where the foregoing comparisons can be made are in the same direction and greater than the probable error in every case and in several instances from five to seven times as large.

To get a better idea of how much reliance should be placed on these differences in yield, odds were calculated by Student's method,[9] using the tables of odds given by Love.[10] The yields of those replicate plots that may be paired for this purpose are given in Table 6.

TABLE 6.— *Yields of seed cotton in pounds per acre of plots used to determine odds by Student's method*

| Kind of fertilizer | Corrected coefficient variability $V$ | Yield (pounds per acre) of replicate plots on— | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Norfolk coarse sand, planting No. 6 | | | | Cecil sandy clay loam, planting No. 7 | | Cecil sandy clay loam, planting No. 8 | |
| 4–8–4 | 0 | 1,108 | 791 | 946 | 599 | 996 | 991 | 1,301 | 1,213 |
| | 7.8 | 813 | 779 | 762 | 934 | 817 | 923 | 1,064 | 1,077 |
| | 55.3 | 956 | 584 | 600 | 651 | 868 | 854 | 1,013 | 1,006 |
| 12–24–12 | 0 | 970 | 548 | 501 | 705 | 1,349 | 1,181 | 1,107 | 1,082 |
| | 19.7 | 888 | 253 | 742 | 467 | 1,376 | 1,247 | 890 | 962 |
| | 66.2 | 481 | 220 | 532 | 384 | 1,226 | 1,022 | 893 | 691 |

The figures in any line may be paired with those in the same vertical columns of either of the other two lines given for the same fertilizer. Accordingly, eight pairs of figures from three plantings on two widely different types of soil were used in calculating the significance of the differences of the average yields. The differences in yields between the pairs may be considered as due primarily to the method of application and secondarily to soil differences, and those between the yields in the same line primarily to soil variance. The odds, as calculated by Student's method, that the uniform applications are really superior to the most irregular applications in increasing yields, are 488 to 1 and 529 to 1 for the 4–8–4 and 12–24–12 fertilizers, respectively. The corresponding odds that uniform distribution is better than that with a coefficient of variability of 7.8 in increasing yields are 9 to 1, and those that the distribution with a coefficient of 19.7 is superior to that with a coefficient of 66.2 are 22.8 to 1. In every case the odds are in favor of the greater degree of uniformity of distribution. This fact, together with the size of the odds, makes it practically certain that the major part of the average differences in yield are due to the degree of variability of distribution of the fertilizer.

Coefficients of correlation were computed for each fertilizer to determine the extent to which fluctuations in yield correspond to those of $V$. The averages of the actual yields obtained in the three plant-

[9] ANONYMOUS. THE PROBABLE ERROR OF A MEAN. By Student. Biometrika 6:1–25, illus. 1908.
[10] LOVE, H. H. A MODIFICATION OF STUDENT'S TABLE FOR USE IN INTERPRETING EXPERIMENTAL RESULTS. Jour. Amer. Soc. Agron. 16: 68–73. 1924.

ings and the original values of $V$ were used first. When the data for the 4–8–4 fertilizer, the 12–24–12, and both simultaneously, are correlated, $r = -0.840 \pm 0.081$, $-0.665 \pm 0.153$, and $-0.704 \pm 0.098$. For the corrected figures $r = -0.894 \pm 0.055$, $-0.810 \pm 0.095$, and $-0.795 \pm 0.072$, respectively. The latter coefficients are better, and their size indicates that if these experiments were repeated under the same conditions, differences in yield might be predicted from the degrees of variability of distribution of the fertilizer by means of a regression equation with an accuracy of about 70 per cent.

## TIME OF MATURITY

Both fertilizers greatly hastened maturity, as shown by comparisons between the results from fertilized and unfertilized plots. The uniformly applied fertilizers not only produced more cotton, but in nearly every instance they also hastened maturity to a greater extent than the same fertilizers applied irregularly. In the few cases of irregular distribution, where a greater percentage of the crop was mature at the first picking, the total produced was small in proportion to that produced by the corresponding uniformly applied fertilizer.

## DISCUSSION

In this study an ordinary fertilizer applied in a band 2 inches below the seed at planting time at the recommended rate by machines giving a representative range of irregular distribution increased the average yield of three plantings on two different soils by 548 pounds of seed cotton per acre over the yields of the unfertilized checks. When the same quantity of the same fertilizer was evenly distributed the average yield was 652 pounds greater than the checks, or 19 per cent greater than the average for the machines. The corresponding figures when the concentrated fertilizer was used are 452 and 666. In this case 214 pounds of seed cotton to the acre or 47 per cent more crop was produced. The 4–8–4 and 12–24–12 fertilizers were 37 per cent and 73 per cent more efficient in increasing yields, respectively, when uniformly applied than when applied with the greatest degree of irregularity. It is realized that under other conditions the differences might not be so striking, and further studies will be reported elsewhere.[11] Nevertheless, it appears that the degree of variability of distribution of fertilizers is a factor of importance in the production of cotton.

Any additional expense that might be incurred by the farmer, in obtaining proper equipment, or by manufacturers in refinement of fertilizer distributors and in improvement of the drillability of fertilizers, to secure more uniform distribution would undoubtedly be small compared to the benefits that might be expected.

## SUMMARY

Ordinary and concentrated fertilizers at rates of 800 and 267 pounds per acre, respectively, were applied uniformly by hand and with five typical degrees of irregular distribution by commercial distributors in barrow bands 2 inches below cottonseed in Norfolk coarse sand and

[11] The later report has been published since this was written. See CUMMINGS, G. A., MEHRING, A. L., LEWIS, G. H., and SACHS, W. H. PROGRESS REPORT ON MECHANICAL APPLICATION OF FERTILIZERS TO COTTON IN SOUTH CAROLINA, 1930. U. S. Dept. Agr. Circ. 192, 31 p., illus. 1931.

Cecil sandy clay loam. A statistical analysis was made of measurements of the crops produced.

The results indicate that a larger number of seed germinate promptly but the seedlings are more irregularly spaced along the row when fertilizers are irregularly applied than when they are uniformly distributed.

More rapid and uniform growth, earlier blooms, earlier maturity, and larger yields of cotton were produced by uniform applications than by irregular ones. The extent of these effects was decidedly significant and varied with the degree of irregularity of distribution.

# ACETIC ACID AND PYROLIGNEOUS ACID IN COMPARISON WITH FORMALDEHYDE AS SOIL DISINFECTANTS[1]

By WILLIAM L. DORAN

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## INTRODUCTION

Formaldehyde is one of the most commonly used of soil disinfectants. Its efficacy against fungi in the soil is well established, but it has at least two faults. The cost of the treatment is relatively high and the time which must be allowed to elapse between treatment and seeding, if the treatment is not to injure germination, is sometimes objectionable. The principal object of the work here described was to find a soil disinfectant as effective against fungi, lower in cost, and less injurious to seeds than is formaldehyde.

In earlier experiments, the results of which have been described by the writer,[2] 1.0 to 1.2 per cent acetic acid used as a soil disinfectant was found to protect seedlings from damping off. Similar results with acetic acid as a soil disinfectant have since been secured by other investigators.[3] [4]

The evidence presented in this paper verifies the conclusions previously reached in regard to acetic acid and serves as a basis for comparing acetic acid, pyroligneous acid, and formaldehyde as soil disinfectants. In the present paper various dilutions and rates of application of acetic acid, pyroligneous acid, and formaldehyde are compared with each other as regards prevention of damping off (caused by species of Pythium and Rhizoctonia), effect on seed germination, and effect on growth (dry weight) of plants.

## METHODS

The soil used is a water-deposited fine sandy loam. In all cases (except in a forest nursery, to which reference is made below) manure was composted with this soil as in ordinary greenhouse practice. The soil prior to the application of the treatments contained water to the extent of 60 per cent of its water-holding capacity (except as otherwise indicated).

For each series of experiments, all seeds were sown the same day, in order that the effects of the treatments on growth of plants might be compared. Treatments were in triplicate and 900 seeds of beet, cucumber, and lettuce were used for each. Seeds were sown at the rate of 50 per linear foot. After germination was completed and damping off had ceased, seedlings were thinned so as to leave the same number per linear foot, in order that competition between plants should not interfere with the effects of soil treatment on growth.

[1] Received for publication Oct. 26, 1931; issued May, 1932. Contribution No. 126 of the Massachusetts Agricultural Experiment Station.

[2] DORAN, W. L. ACETIC ACID AS A SOIL DISINFECTANT. Jour. Agr. Research 36: 269–280, illus. 1928.

[3] ANDERSON, P. J., SWANBACK, T. R., and STREET, O. E., and others. DAMPING OFF OF YOUNG TOBACCO SEEDLINGS. Conn. Agr. Expt. Sta. Bul. 311: 269–270, illus. 1930.

[4] SLATE, W. L. BOTANY. Conn. Agr. Expt. Sta. Bul. 318: 757. 1930.

Three weeks later the plants were pulled, washed, and dried to constant weight.

The dilutions of pyroligneous acid, acetic acid, and formaldehyde which were applied to soil are recorded in Table 1, as are also the intervals of time which elapsed after soil treatment and before seeding. Except as is otherwise indicated, the diluted chemicals were applied to soil at the rate of 2½ quarts per square foot.

Undistilled pyroligneous acid was used. As described by the manufacturers, it was made by the destructive distillation of hardwood (beech, birch, and maple) in sealed retorts. Pyroligneous acid was found to have certain advantages over either acetic acid or formaldehyde as a soil disinfectant, and the results are accordingly presented. Further work will, however, be necessary before the observed effects of pyroligneous acid on fungi in the soil can be traced to each of its several constituents, since, according to Hawley,[5] pyroligneous acid is not a chemical compound but contains a number of constituents, including acetic acid, methyl alcohol, formaldehyde, and furfural.

TABLE 1.—*Effects of formaldehyde, acetic acid, and pyroligneous acid on seed germination, damping off of seedlings, and dry weights of plants*

| Soil treatment | Time interval between soil treatment and seeding | Germination of seeds of different plants | | | Plant seedlings which damped off | | | Dry weights of 100 plants | |
|---|---|---|---|---|---|---|---|---|---|
| | | Beet [a] | Cucumber | Lettuce | Beet | Cucumber | Lettuce | Beet | Cucumber |
| | *Days* | *Number* | *Per cent* | *Per cent* | *Per cent* | *Per cent* | *Per cent* | *Grams* | *Grams* |
| Check | | 83 | 60 | 45 | 40 | 61 | 45 | 16.61 | 30.50 |
| Formaldehyde 1:50 | 10 | 129 | 84 | 45 | 0 | 0 | 0 | 20.78 | 94.85 |
| Acetic acid 1.19 per cent | 5 | 129 | 100 | 72 | 0 | 0 | 0 | | 111.27 |
| Do | 13 | 138 | 85 | 60 | 0 | 0 | 0 | 20.79 | |
| Acetic acid, 1.78 per cent | 13 | 40 | | | 0 | | | 20.58 | |
| Pyroligneous acid, 1:100 | 12 | | | | 1 | 29 | | 35.00 | |
| Pyroligneous acid, 2:100 | 1 | 120 | 92 | 56 | 0 | 0 | 0 | | |
| Do | 2 | 136 | 89 | 63 | 0 | 0 | 0 | | 113.50 |
| Do | 3 | 107 | 80 | 80 | 0 | 16 | 0 | | |
| Do | 5 | 86 | 93 | 75 | 17 | 4 | 7 | | |
| Do | 13 | 149 | | | 6 | | | 23.69 | |
| Pyroligneous acid, 3:100 | 1 | 128 | 72 | 49 | 0 | 0 | 0 | | |
| Do | 2 | 83 | 93 | 57 | 2 | 0 | 0 | | 118.93 |
| Do | 3 | 108 | 81 | 72 | 0 | 0 | 0 | | |
| Do | 6 | 92 | 80 | 53 | 0 | 0 | 0 | | |
| Do | 13 | 139 | | | 3 | | | 22.66 | |
| Pyroligneous acid, 4:100 | 1 | 128 | 97 | 60 | 0 | 0 | 0 | | |
| Do | 2 | 108 | 73 | 56 | 0 | 0 | 0 | | 125.28 |
| Do | 3 | 155 | 97 | 68 | 0 | 0 | 0 | | |
| Do | 5 | 124 | 72 | | 0 | 0 | 0 | | |
| Do | 7 | 124 | 83 | 45 | 0 | 0 | 0 | | |
| Do | 13 | 141 | | | 0 | | | 17.26 | |
| Pyroligneous acid, 5:100 | 13 | | | | 0 | 0 | | | 38.73 |
| Pyroligneous acid, 10:100 | 13 | | | | 0 | 0 | | 27.40 | |

[a] Number of seedlings which came up for each 100 beet seed balls sown.

[5] HAWLEY, L. F. WOOD DISTILLATION. 141 p., illus. New York. 1923.

## EFFECTS OF SOIL DISINFECTANTS ON DAMPING OFF OF SEEDLINGS

The average percentages of seeds which germinated, seedlings which damped off, and dry weight of plants are recorded in Table 1. Damping off was severe in untreated soil, for in it 40 per cent of the beet seedlings, 61 per cent of the cucumber seedlings, and 45 per cent of the lettuce seedlings damped off. There was no damping off in

soil to which formaldehyde 1:50 (1 gallon of formaldehyde with 49 gallons of water) had been applied 10 days before seeding.

All damping off of the seedlings of beet, cucumber, and lettuce was also prevented by acetic acid 1.19 per cent applied to soil 5 or 13 days before seeding and at the rate of 2½ quarts per square foot. In other experiments conducted by the writer damping off has been prevented equally well by acetic acid 1.19 per cent applied to soil at the rate of 2 quarts per square foot. Thus used, the cost of the acetic-acid treatment, per unit area of soil, is about three-fourths of the cost of soil treatment with formaldehyde.

In connection with this use of acetic acid, experiments with vinegar as a soil disinfectant were undertaken, for vinegar is, of course, readily available to every farmer and gardener. The user of vinegar is relatively certain of obtaining a standardized product as regards content of acetic acid, for, according to the standard adopted in enforcing the Federal food and drug act,[6] cider or apple vinegar (also grape or wine vinegar, malt vinegar, sugar vinegar, glucose vinegar, and spirit vinegar) must contain not less than 4 g of acetic acid per 100 cc. Such vinegar when diluted by the addition of 2½ parts of water to 1 part of vinegar (by volume) will, therefore, contain in this dilution about 1.16 per cent acetic acid. Vinegar thus diluted was applied to soil (at the rate of 2 quarts per square foot), and 10 days later tobacco seeds were sown in the treated soil and in soil not treated. Seeds germinated well (equally well in both cases), and as may be seen by reference to Figure 1, there was no damping off in soil to which vinegar had been applied, although the disease was severe in the untreated soil.

In earlier experiments,[7] seedlings of white spruce were protected against damping off by 1.12 per cent acetic acid applied to soil at the rate of 1.64 quarts per square foot seven days before seeds were sown. With the object of improving upon this method for use in forest nurseries, acetic acid (0.47 to 0.80 per cent) was applied to seed beds, at the rate of three-fourths of a quart per square foot, immediately after the seeds of red or Norway pine (*Pinus resinosa* Sol.) were sown. Damping off was severe in the untreated soil. Living seedlings (in 4 square feet of each seed bed) were counted three months after the date of seeding. The results are recorded in Table 2. Seed germination was improved, damping off was controlled, and the number of seedlings living three months after seeding was increased most (more than 700 per cent) by 0.8 per cent acetic acid (4.2 pounds of 80 per cent acetic acid diluted with water to 50 gallons) applied to the soil at the rate of three-fourths quart per square foot immediately after seeding. The merits of this treatment for the prevention of damping off in a forest nursery are the successful control of damping off, the harmlessness to seeds (of red pine), the relatively small amount of water, and therefore of labor, needed, and the avoidance of delay between soil treatment and seeding.

[6] UNITED STATES DEPARTMENT AGRICULTURE, FOOD AND DRUG ADMINISTRATION. DEFINITIONS AND STANDARDS FOR FOOD PRODUCTS. U. S. Dept. Agr., Food and Drug Admin. Ser. and Regulat. Announc., Food and Drug No. 2 (second revision), 19 p. 1931.

[7] DORAN, W. L. Op. cit. (See footnote 2.)

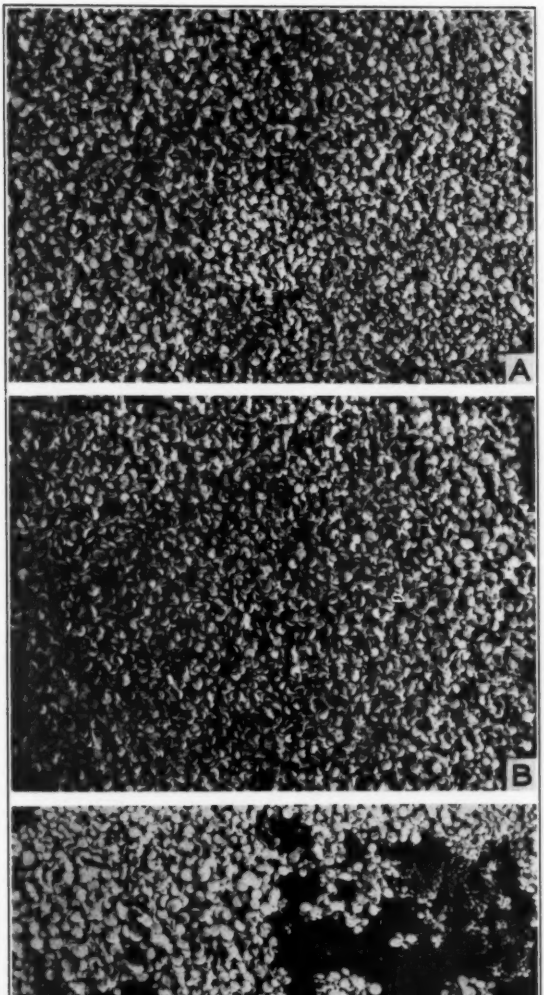


FIGURE 1.—Tobacco seedlings protected against damping off by soil treatment with pyroligneous acid and with vinegar: A, Pyroligneous acid, 2:100, applied to soil at the rate of 2 quarts per square foot (7 days before seeding); B, vinegar, 1 part with water 2½ parts (by volume) applied to soil at the rate of 2 quarts per square foot (10 days before seeding); C, check, no disinfectant used

TABLE 2.—*Effects of soil treatment with various strengths of acetic acid on the damping off of the seedlings of red pine*

| Percentage of acetic acid applied to soil | Living seedlings per square foot (3 months after seeding) | Increase in seedlings per unit area as compared with check | Percentage of acetic acid applied to soil | Living seedlings per square foot (3 months after seeding) | Increase in seedlings per unit area as compared with check |
|---|---|---|---|---|---|
| | *Number* | *Per cent* | | *Number* | *Per cent* |
| 0 (check) | 37 | | 0.33 | 236 | 538 |
| 0.47 | 163 | 340 | 0.80 | 301 | 713 |
| 0.67 | 265 | 616 | | | |

All damping off of seedlings listed in Table 1 was prevented by pryoligneous acid 10:100, 5:100, and 4:100.[8] Pyroligneous acid 3:100 prevented all damping off of cucumber and lettuce seedlings, but there was a little damping off of beet seedlings, 2 to 3 per cent, in soil to which pyroligneous acid 3:100 had been applied. In these experiments, pyroligneous acid 4:100 was as effective in preventing all damping off as was formaldehyde 1:50 or acetic acid 1.19 per cent. In other experiments, damping off of seedlings was controlled equally well by pyroligneous acid 3½:100, applied to soil at the rate of 2 quarts per square foot. Thus used, the cost of soil treatment with pyroligneous acid 3½:100 was about 58 per cent of the cost, per unit area, of soil treatment with formaldehyde 1:50.

In the experiments recorded in Table 1 pyroligneous acid 1:100 or 2:100 did not prevent all damping off of the seedlings of beet, cucumber, and lettuce. These concentrations are considered too dilute to be dependable, although in some cases pyroligneous acid 2:100 has given adequate protection. When pyroligneous acid 2:100 was applied to soil at the rate of 2 quarts per square foot seven days before tobacco seeds were sown there was, as may be seen by reference to Figure 1, no damping off of tobacco seedlings grown in soil so treated, although the disease was severe in untreated soil.

## EFFECTS OF SOIL DISINFECTANTS ON SEED GERMINATION

In the untreated soil 60 per cent of the cucumber seeds and 45 per cent of the lettuce seeds germinated and 83 beet seedlings came up for each 100 beet seed balls sown. Much of this poor germination was due to the decay of seeds resulting from the attack of damping-off fungi in the soil.

The germination of the seeds of beet and cucumber was improved, and the germination of the seeds of lettuce was unaffected by formaldehyde 1:50 applied to the soil 10 days before seeding.

The germination of the seeds of beets was injured by 1.78 per cent acetic acid, and on the basis of these and other experiments it is not considered necessary to use a greater concentration of acetic acid than 1.2 per cent for soil disinfection.

The germination of these seeds was improved as much, or more, by 1.19 per cent acetic acid as by formaldehyde, and this was the case in the experiments represented in Table 1, whether acetic acid

[8] Dilutions of pyroligneous acid to which reference is made in the text and in Table 1 are indicated as number of parts (by volume) of pyroligneous acid in 100 parts of water.

was applied to the soil 5 days or 13 days before seeding. In other experiments by the writer seed germination has sometimes been injured, however, if seeds were planted in less than 10 days after the application of acetic acid to soil, and this is considered the minimum time interval before seeding which is usually safe after soil treatment with either acetic acid or formaldehyde.

In the case of tobacco seed beds the delay which must follow the application of these soil treatments in the spring is sometimes objectionable. This is of course avoidable by applying such treatments in the fall; and, as observed by the writer, best results have been secured in tobacco seed beds when the soil was disinfected with acetic acid in the fall rather than in the spring.

Chemical soil disinfection of tobacco seed beds in the spring may have another disadvantage, for if the soil is very wet, as it often is at that season, neither acetic acid nor formaldehyde as ordinarily applied always prevents all damping off. Earlier investigators[9] have suggested applying formaldehyde to tobacco seed beds in the fall rather than in the spring if the soil is likely to be very wet. Their conclusions are supported by the results of experiments by the writer, in which formaldehyde 1:50 (2 quarts per square foot) was less effective in preventing damping off when applied to water-saturated soil than it was when applied to soil which, previous to treatment, contained water to the extent of 50 per cent of its water-holding capacity.

As may be seen by reference to Table 1, the germination of the seeds of beet, cucumber, and lettuce was in most cases improved and in no case injured by soil disinfection with pyroligneous acid 2:100, 3:100, and 4:100. Seeds were uninjured even though the interval between soil treatment with pyroligneous acid 3:100 or 4:100 and seeding was reduced to one or two days. In other experiments it was, however, found unsafe to shorten this interval to less than one day or to apply pyroligneous acid 2:100, 3:100, or 4:100 to living plants. When these treatments were applied, at the rate of 1 quart per square foot, to seedlings of beet, cucumber, and lettuce which had begun to damp off, the plants were severely injured. When pyroligneous acid 3:100 was applied to soil at the rate of 2 quarts per square foot, at the same time that the seeds of pepper, lettuce, cucumber, and tomato were sown, the germination of the seeds of cucumber and tomato was unaffected, but the germination of the seeds of pepper and lettuce was injured.

These observations lead to the conclusion that pyroligneous acid like acetic acid or formaldehyde should be applied to the soil before sowing most seeds. But in the experiments above described and with the seeds used it was safe to apply pyroligneous acid to the soil as late as one day before seeding, and this is a matter of convenience which is sometimes important in practice.

## EFFECTS OF SOIL DISINFECTANTS ON DRY WEIGHT OF PLANTS

By reference to Table 1 the dry weight of beet and cucumber seedlings in each of the several soil treatments may be compared with the dry weight of plants in untreated soil. There was considerable increase in dry weight of plants following most treatments, and it was greater with cucumber than with beet.

[9] SELBY, A. D., HOUSER, T., and HUMBERT, J. G. HOW TO DISINFECT TOBACCO PLANT BEDS FROM ROOT-ROT FUNGUS (THIELAVIA). Ohio Agr. Expt. Sta. Circ. 156, 5–8, illus. 1915.

The dry weight of plants was increased by the application of formaldehyde to the soil 10 days before seeding. Acetic acid 1.19 per cent was no less beneficial, for in soil to which it had been applied the dry weight of cucumber seedlings was increased more and the dry weight of beet seedlings was increased as much as by formaldehyde. In these, as in other experiments, the application of acetic acid 1.19 per cent, at the rate of 2 or 2½ quarts per square foot of soil, was followed by an improved growth of plants, and the improvement in growth was ordinarily as great as that associated with the use of formaldehyde. Even the use of acetic acid 1.78 per cent, a concentration which may injure seed germination, was without any injurious effect on the growth of beets in soil to which this treatment had been applied 13 days before seeding.

There was no retarding of growth of plants in soil to which pyroligneous acid 1:100, 2:100, 3:100, 4:100, 5:100, and 10:100 had been applied, even though the treatments with pyroligneous acid 2:100, 3:100, and 4:100 were applied to soil only one or two days before seeding. Dry weight of cucumber seedlings was increased more by pyroligneous acid 3:100 or 4:100 applied to soil two days before seeding than by formaldehyde 1:50 applied to soil 10 days before seeding. The dry weight of beet seedlings was also increased by these treatments, and the increase, as compared with that which followed the use of formaldehyde, was greater with pyroligneous acid 3:100 and less with pyroligneous acid 4:100. In these and in other experiments by the writer the beneficial effect of soil treatment with pyroligneous acid on growth of plants was no less than with formaldhyde.

## SUMMARY

Acetic acid was as safe and as effective a soil disinfectant as formaldehyde, and the cost of soil disinfection with acetic acid was less than with formaldehyde. Damping off of seedlings (of beet, cucumber, and lettuce) was prevented without injury to seed germination and with benefit to growth of plants by soil treatment with 1.19 per cent acetic acid (1 gallon of 56 per cent acetic acid or 2¾ quarts of 80 per cent acetic acid with water to total 50 gallons), applied at the rate of 2 to 2½ quarts per square foot of soil. An application of 2 quarts per square foot was usually enough.

Best results with acetic acid against soil-borne fungi in tobacco seed beds have been secured when the soil was treated in the fall rather than in the spring.

With acetic acid, as with formaldehyde, it was necessary that there be some interval of time, usually 10 days, between soil treatment and seeding; otherwise seed germination was injured.

Damping off of seedlings (of tobacco) was prevented with no injury to germination by vinegar 1 part diluted with water 2½ parts (by volume), applied to soil at the rate of 2 quarts per square foot 10 days before seeding.

Seedlings of red or Norway pine were protected against damping off, and germination was not injured by acetic acid 0.8 per cent (equal to 6 pounds of 56 per cent acetic acid or 4.2 pounds of 80 per cent acetic acid with water to total 50 gallons), applied to soil at the rate of three-fourths of a quart per square foot at the time of seeding.

Pyroligneous acid 3:100 to 4:100 applied to soil at the rate of two quarts per square foot protected seedlings from damping off, and this treatment did not injure the germination of the seeds of beet, cucumber, and lettuce even when it was applied to the soil as late as one day before seeding. Soil treatment with pyroligneous acid resulted in an increase in the dry weight of plants. Per unit area of soil treated, the cost with pyroligneous acid was less than with either formaldehyde or acetic acid. Pyroligneous acid was as effective a soil disinfectant as formaldehyde or acetic acid, and safer and cheaper than either.

# THE INFLUENCE OF PHOSPHATES ON THE PHOSPHORIC ACID CONTENT OF THE PLANT[1]

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## REVIEW OF PREVIOUS INVESTIGATIONS

During the last 15 or 20 years much attention has been given to the matter of improving pastures in this country as well as in Europe. This in turn has led to renewed interest in the mineral requirements of animals and to a study of the so-called mineral deficiency in pastures and feeding materials. Orr [2] cites McDougall's estimate that the value of the grassland products annually consumed in Great Britain is roughly 426,000,000 pounds. He further says:

> Considerably more than half of these is imported, the imports forming nearly a quarter in money value of our total imports * * *. In the British Isles there are 34,000,000 acres of grass of one kind or another, and there are numerous tracts of pasture lands in the Dominions and Colonies. As pasture is the raw material of many of the primary necessities of life, for which there is a constant market, the improvement and better exploitation of these pastures is one of the surest methods of securing the stable prosperity of the Empire.

Recently much interest has centered in the influence of fertilizers on the mineral composition of the plant. An attempt has been made to find out to what extent the low value of certain pastures is due to mineral deficiences in the soil. In this connection Russell [3] says:

> Phosphate starvation markedly affects the composition of crops, lowering their nutritive value to animals and their special quality values to men. Over large areas of the world, soils are very deficient in phosphate. Those occurring in parts of South Africa carry a natural herbage which causes deficiency diseases in cattle; the affected animals devour bones with great eagerness, even putrefying bones when the deficiency is pronounced, so that they become liable to a particular ptomaine poisoning. The obvious remedy is to feed the cattle with bone meal. Similar diseases occur in Australia, where also the arable land shows astonishing benefits from small dressings of superphosphate. In the Romney Marsh the best fatting pastures are richer in phosphates than the poorer ones; this is generally true of England and France.

Investigations in New Zealand have shown that basic slag and superphosphate applied to land that is deficient in phosphoric acid resulted in increasing the percentage of phosphoric acid in grasses. The influence of the superphosphate was most marked in the early spring, but its effect was noted throughout the season. Orr and Scherbatoff [4] have reported at length on some of the problems relating to the influence of mineral fertilizers on the composition of pasture grasses. Their investigations led them to conclude that

> the mineral composition of pasture is affected by the composition of the soil on which it grows, and that the alteration of the composition of the soil by the application of fertilizers increases the mineral content of the pasture, the increase

[1] Received for publication Oct. 26, 1931; issued May, 1932

[2] ORR, J. B., and SCHERBATOFF, H. MINERALS IN PASTURES AND THEIR RELATION TO ANIMAL NUTRITION. p. 1–2. London. 1929.

[3] RUSSELL, E. J. SOIL CONDITIONS AND PLANT GROWTH. Ed. 5, p. 81. London, New York [etc.]. 1927.

[4] ORR, J. B., and SCHERBATOFF, H. Op. cit., p. 48.

being most marked in poor soils. The increase is due partly to the fact that the individual plants are enriched, and partly to the fact that the fertilizers promote the growth and spread of species of plants which are naturally richer in minerals.

Studies made in various parts of the United States have shown that soils which are naturally rich produce grasses high in mineral constituents. It has also been shown that when phosphates are applied to poor soils the phosphoric acid content of the crop is generally increased. In studying this problem, several investigators have noted that the mineral treatment may distinctly influence the type of vegetation. It has likewise been noted that the composition of the vegetation depends more or less upon the date of cutting. Very young grass may contain a high percentage of phosphorus, but on account of the small yield in the early part of the season the total phosphorus that could be obtained by grazing cattle may be small.

Crowther and Ruston [5] found that in the majority of cases the percentage of phosphoric acid decreased up to and including the third cutting. Their results have been confirmed by others, although work done at the New Jersey Agricultural Experiment Station indicates a somewhat higher percentage of phosphoric acid in the mixed herbage of July, August, and September than was found in herbage cut in the early part of the season.

## EXPERIMENTAL WORK

As a further contribution to this subject it seemed worth while to make a study of the phosphate content of crop samples from the cylinder experiments and the soil-fertility plots of this station. The original cylinder soils have received definite fertilizer treatment for 32 years, and the field plots for 22 years.

If mineral fertilizers influence the mineral composition of the plant, surely crops grown on soils without phosphate or with definite phosphate treatment for so long a time should give some evidence of such treatment. Therefore phosphoric acid has been determined in a number of crop samples from the field and cylinder experiments in which phosphates have been used for a number of years. Determinations have been made on the following crops: Wheat and oats, both grain and straw; corn, grain and stover; corn forage; timothy hay; rye, grain and straw; young rye (samples collected in the late fall); soybean hay; barley, grain and straw; barley (grain and straw together); rape; potatoes. Tables showing the different phosphate treatments and the percentage of phosphoric acid in the crop are given. Unless otherwise specified, nitrogen was used in quantities equivalent to 320 pounds of nitrate of soda an acre and potash in quantities equivalent to 320 pounds an acre.

### CYLINDER EXPERIMENT WITH OATS AND CORN

Oats and corn were grown in Penn loam soil in cylinders without fertilizer and with different fertilizing materials, this soil having been under cultivation and treatment for about 30 years. The soils of one series were limed at intervals of 5 years, while those of the other series were limed and also produced two legume green-manure crops in the

[5] CROWTHER, C., and RUSTON, A. G. THE INFLUENCE OF TIME OF CUTTING UPON YIELD AND COMPOSITION OF HAY. Jour. Agr. Sci. [England] 4: 305-317. 1912.

course of the 5-year rotation. The crop was analyzed for phosphoric acid with the results shown in Table 1. In this case plants grown in the cylinders without treatment showed the lowest percentage of phosphoric acid. Those with minerals or minerals and nitrate of soda showed a distinct increase in phosphoric acid, while those that received minerals, nitrate of soda, and manure showed an increase of as much as 40 per cent. A smaller but distinct increase was noted in the oats grain where minerals and nitrate were used on field plots. (Table 8.) The difference between those with lime and those with lime and green manure is scarcely significant.

TABLE 1.—*Phosphoric acid content of oats (grain and straw) and corn (forage) grown in cylinders with different fertilizer treatments, 1930*

| Cylinder No. | Fertilizer treatment | Phosphoric acid content (per cent) of crops grown on— | | | |
|---|---|---|---|---|---|
| | | Limed plots (B's) | | Limed plots with green manure added (C's) | |
| | | Oats | Corn | Oats | Corn |
| 1 | No fertilizer | 0.978 | 0.860 | 0.937 | 0.868 |
| 2 | Minerals * | 1.237 | .929 | 1.174 | 1.192 |
| 3 | Minerals and manure | 1.330 | 1.365 | 1.330 | 1.296 |
| 7 | Minerals and nitrate of soda | 1.162 | 1.122 | 1.145 | 1.157 |
| 8 | Minerals and double nitrate of soda | 1.150 | 1.019 | 1.128 | 1.019 |
| 9 | Minerals, nitrate, and manure | 1.375 | 1.145 | 1.318 | 1.110 |
| 10 | Minerals, double nitrate, and manure | 1.336 | 1.122 | 1.342 | 1.019 |
| 17 | Minerals and ammonium sulphate | 1.133 | 1.068 | 1.168 | 1.088 |
| | Average | 1.213 | 1.081 | 1.193 | 1.094 |

* Minerals=640 pounds of superphosphate and 320 pounds of muriate of potash per acre.

CYLINDER EXPERIMENT ON THE INFLUENCE OF NITROGEN, PHOSPHORIC ACID AND POTASH ON THE PHOSPHORIC ACID CONTENT OF BARLEY

In growing barley in Sassafras silt loam in cylinders, phosphoric acid in the form of superphosphate was used in three different quantities, with a single and also a double portion of potash, and with different nitrogenous materials furnishing equivalent amounts of nitrogen. The fertilizer treatment on this soil was begun in 1923. The 1930 crop was harvested just before maturity, and determinations were made on the grain and straw together. The results are shown in Table 2. The double and triple phosphate treatments produced slight increases in the phosphoric acid content of barley as compared with the single treatment. The differences between the single and double potash treatments are not significant. In every case the plants from the cylinders that did not receive nitrogen showed a higher percentage of phosphoric acid in the dry matter than did those that received nitrogen. The plants in the cylinders that received nitrate of soda showed a higher percentage of phosphoric acid than did those receiving the other nitrogenous materials. With slight exceptions, the percentages varied from about 0.7 to a little over 1 per cent $P_2O_5$. This soil originally (1922) contained about 0.11 per cent $P_2O_5$.

TABLE 2.—*Phosphoric acid content of barley when fertilized with different nitrogenous materials, and with different quantities of phosphoric acid and potash, 1930*

| Nitrogen treatment | Phosphoric acid content (per cent) of barley grown with— | | | | | |
|---|---|---|---|---|---|---|
| | Single $P_2O_5$ treatment and— | | Double $P_2O_5$ treatment and— | | Triple $P_2O_5$ treatment and— | |
| | Single $K_2O$ treatment | Double $K_2O$ treatment | Single $K_2O$ treatment | Double $K_2O$ treatment | Single $K_2O$ treatment | Double $K_2O$ treatment |
| No nitrogen | 1.038 | 0.894 | 1.090 | 1.113 | 1.136 | 1.060 |
| Nitrate of soda | .923 | .796 | .980 | .958 | .814 | .808 |
| Sulphate of ammonia | .704 | .710 | .825 | .681 | .814 | .813 |
| Dried blood | .745 | .652 | .849 | .831 | .883 | .935 |
| ⅓ nitrogen from each of above three | .750 | .687 | .774 | .808 | .882 | .837 |
| Average | .781 | .711 | .857 | .820 | .848 | .848 |

CYLINDER EXPERIMENT ON THE INFLUENCE OF PHOSPHATE ON THE PHOSPHORIC ACID CONTENT OF CORN FORAGE GROWN ON SOILS VARYING IN MECHANICAL COMPOSITION

Corn forage was grown on soils varying in mechanical composition and with varying amounts of fertilizer, and samples of the dry material were analyzed for phosphoric acid. The results of the work are given in Table 3. The average phosphoric acid content of the dry matter for the crop grown on loam soil was 0.535 per cent; for the crop on loam soil with 20 per cent of sand the average was 0.634 per cent, and for the crop on loam soil with 40 per cent of sand it was 0.549 per cent. The average phosphoric acid content of dry matter of the crop grown in cylinders without fertilizer was slightly over 0.7 per cent. With fertilizer at the rate of 200 pounds an acre the average was 0.6 per cent, and with fertilizer at the rate of 500 and 1,000 pounds an acre it was about 0.5 per cent $P_2O_5$. It will be noted that the dry matter of the forage grown in cylinders with 20 per cent of sand showed a higher percentage of phosphoric acid than did that of forage grown on loam soil or on loam soil with 40 per cent of sand. In the fertilizer-treatment experiments, the forage grown in cylinders receiving no fertilizer had a higher average percentage of phosphoric acid than did that grown in cylinders receiving fertilizer. Forage in cylinders receiving fertilizer at the rate of 200 pounds an acre had a higher average percentage of phosphoric acid than did that in cylinders receiving 500 and 1,000 pounds of fertilizer an acre. This is not in agreement with other work reported here. Attention has already been called to the fact that in a number of cases heavy applications of superphosphate resulted in some increase in the phosphoric acid content of the crop. In this case, however, the yield of dry matter was very much increased as the amount of fertilizer applied was increased, and this resulted in a proportionate increase in the amount of phosphoric acid removed in the crop. It is therefore possible that this increased demand for phosphoric acid drew so heavily on the available supply in the soil as to cause a reduction in the percentage in the dry matter of the crop. This seems the only explanation for a lowered percentage in the dry matter where the phosphate application was increased.

TABLE 3.—*Phosphoric acid content of corn forage grown on soils varying in mechanical composition, with and without fertilizer (cylinder experiment), 1930*

| Fertilizer treatment[a] (pounds per acre) | Dry matter in and phosphoric acid content of corn forage grown on— | | | | | | | | | Average | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Loam soil | | | Loam soil 80 per cent, and sand 20 per cent | | | Loam soil 60 per cent, and sand 40 per cent | | | | | |
| | Dry matter | Phosphoric acid | | Dry matter | Phosphoric acid | | Dry matter | Phosphoric acid | | Dry matter | Phosphoric acid | |
| | *Gm* | *Per cent* | *Gm*[b] | *Gm* | *Per cent* | *Gm*[b] | *Gm* | *Per cent* | *Gm*[b] | *Gm* | *Per cent* | *Gm*[b] |
| Without fertilizer | 150 | 0.681 | 1.021 | 135 | 0.762 | 1.031 | 108 | 0.682 | 0.735 | 131 | 0.708 | 0.929 |
| 200 | 201 | .546 | 1.095 | 200 | .664 | 1.324 | 176 | .593 | 1.049 | 192 | .601 | 1.156 |
| 500 | 254 | .446 | 1.130 | 277 | .593 | 1.637 | 255 | .431 | .945 | 262 | .490 | 1.237 |
| 1,000 | 373 | .468 | 1.744 | 405 | .517 | 2.099 | 376 | .491 | 1.863 | 385 | .492 | 1.902 |
| Average | 245 | .535 | 1.248 | 254 | .634 | 1.523 | 229 | .549 | 1.148 | 243 | .573 | 1.306 |

[a] The fertilizer used analyzed 16 per cent, $NH_3$, 18 per cent $P_2O_5$, and 16 per cent $K_2O$ made from urea, high-grade superphosphate, and muriate of potash. Half the fertilizer was applied at planting, and half near the end of July.

[b] Grams removed from soil.

### CYLINDER EXPERIMENT ON THE INFLUENCE OF PHOSPHATES ON THE PHOSPHORIC ACID CONTENT OF RYE, SOYBEAN HAY, AND BARLEY

In cylinder experiments rye was grown on two types of soil, Sassafras loam and Portsmouth loam, with varying amounts of superphosphate and also with raw rock phosphate in equivalent amounts. Phosphoric acid determinations were made on grain and straw, with the results shown in Table 4. In nearly all cases the grain and straw from the cylinders that received the heavier applications of superphosphate showed some increase in phosphoric acid over those that received no phosphate treatment.

With the raw rock phosphate the increases over the no-phosphate treatment were slight. There was little difference between the phosphoric acid content of samples from the limed and unlimed sections.

Soybeans for hay were also grown on these two soils and on a third soil, Colts Neck loam, with the same phosphate treatment. Results are shown in Table 5 for the 1923 crop and in Table 6 for the 1930 crop. Determinations of phosphoric acid in rape grown on Colts Neck loam, with the same fertilizer treatment as the soybeans, are also shown in Table 6.

When 100 and 200 pounds of superphosphate were applied to the acre there was very little increase in the phosphoric acid content of the dry matter, but when 500 and 1,000 pounds of superphosphate were applied to the acre there was nearly always some increase in the phosphoric acid content of the dry matter.

TABLE 4.—*Phosphoric acid content (per cent) of rye grown on different types of soil under different phosphate treatments, 1923*

SUPERPHOSPHATE SECTION

| Phosphate treatment (pounds per acre) | Phosphoric acid content (per cent) of rye grown— | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | With lime on— | | | | Without lime— | | | |
| | Sassafras loam | | Portsmouth loam | | Sassafras loam | | Portsmouth loam | |
| | Grain | Straw | Grain | Straw | Grain | Straw | Grain | Straw |
| No phosphate | 0.803 | 0.159 | 0.822 | 0.180 | 0.799 | 0.104 | 0.770 | 0.115 |
| 100, superphosphate | .777 | .138 | .765 | .179 | .871 | .122 | .905 | .154 |
| 200, superphosphate | .886 | .143 | .900 | .174 | .952 | .159 | .890 | .151 |
| 500, superphosphate | .902 | .185 | .936 | .213 | .952 | .154 | .936 | .167 |
| 1,000 superphosphate | 1.001 | .190 | .900 | .195 | 1.045 | .174 | .921 | .180 |
| Average | .892 | .164 | .875 | .190 | .955 | .152 | .913 | .163 |

RAW ROCK PHOSPHATE SECTION

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| No phosphate | 0.884 | 0.135 | 0.853 | 0.195 | 0.890 | 0.169 | 0.843 | 0.148 |
| Rock phosphate equivalent to 100 pounds superphosphate | .884 | .156 | .900 | .185 | .895 | .156 | .837 | .138 |
| Rock phosphate equivalent to 200 pounds superphosphate | .819 | .143 | .832 | .203 | .874 | .177 | .864 | .153 |
| Rock phosphate equivalent to 500 pounds superphosphate | .929 | .138 | .780 | .177 | .973 | .164 | .764 | .164 |
| Rock phosphate equivalent to 1,000 pounds superphosphate | .962 | .156 | .874 | .148 | .942 | .161 | .822 | .193 |
| Average | .899 | .148 | .847 | .178 | .921 | .165 | .822 | .162 |

TABLE 5.—*Phosphoric acid content (per cent) of soybean hay grown on different types of soil under different phosphate treatments, 1923*

SUPERPHOSPHATE SECTION

| Phosphate treatment (pounds per acre) | Phosphoric acid content (per cent) of soybean hay grown— | | | | | |
|---|---|---|---|---|---|---|
| | With lime | | | Without lime | | |
| | Colts Neck loam | Sassafras sandy loam | Portsmouth loam | Colts Neck loam | Sassafras sandy loam | Portsmouth loam |
| No phosphate | 0.668 | 0.645 | 0.526 | 0.642 | 0.682 | 0.531 |
| 100, superphosphate | .658 | .665 | .632 | .653 | .668 | .603 |
| 200, superphosphate | .655 | .695 | .582 | .725 | .673 | .611 |
| 500, superphosphate | .682 | .721 | .624 | .668 | .718 | .655 |
| 1,000, superphosphate | .705 | .736 | .640 | .707 | .760 | .658 |
| Average | .675 | .704 | .620 | .689 | .705 | .632 |

RAW ROCK PHOSPHATE SECTION

| | | | | | | |
|---|---|---|---|---|---|---|
| No phosphate | 0.658 | 0.670 | 0.642 | 0.648 | 0.658 | 0.575 |
| Rock phosphate equivalent to 100 pounds superphosphate | .650 | .658 | .611 | .650 | .666 | .619 |
| Rock phosphate equivalent to 200 pounds superphosphate | .642 | .611 | .606 | .679 | .674 | .630 |
| Rock phosphate equivalent to 500 pounds superphosphate | .686 | .684 | .617 | .749 | .710 | .614 |
| Rock phosphate equivalent to 1,000 pounds superphosphate | .668 | .676 | .622 | .715 | .668 | .637 |
| Average | .662 | .657 | .614 | .699 | .680 | .625 |

TABLE 6.—*Phosphoric acid content (per cent) of soybean hay and rape (dry) grown on different types of soil under different phosphate treatments, 1930*

| Phosphate treatment (pounds per acre) | Phosphoric acid content (per cent) of crops | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Soybean hay grown on— | | | | | | Rape (dry matter) grown on— | |
| | Colts Neck loam | | Sassafras sandy loam | | Portsmouth loam | | Colts Neck loam | |
| | A[a] | B | A | B | A | B | A | B |
| No phosphate | 0.605 | 0.652 | 0.439 | 0.468 | 0.595 | 0.566 | 0.894 | 0.885 |
| 100, superphosphate | .640 | .739 | .427 | .560 | .617 | .658 | .900 | .986 |
| 200, superphosphate | .664 | .672 | .468 | .546 | .617 | .710 | .966 | .780 |
| 500, superphosphate | .706 | .718 | .557 | .632 | .721 | .675 | .958 | .853 |
| 1,000, superphosphate | .762 | .640 | .530 | .569 | .715 | .744 | .910 | 1.003 |
| Average | .693 | .692 | .496 | .577 | .668 | .697 | .934 | .906 |

[a] A and B = duplicate treatments.

With raw rock phosphate such increases as are noted were slight and in a number of cases there was no increase. Lime seems to have had little influence one way or the other. With the exception of the soybean hay on Sassafras sandy loam in 1930, the type of soil seems to have had little influence. In this connection it may be explained that the Colts Neck loam is exceptionally high in phosphoric acid—about 0.8 to 1 per cent; the Sassafras sandy loam is rather low in phosphoric acid, whereas the Portsmouth loam also contains a high percentage, though not so high as the Colts Neck loam.

In 1923, barley was grown on Colts Neck loam with and without lime, with the phosphate treatments outlined above. Phosphoric acid was determined in the grain and straw, with the results shown in Table 7. In this case neither the phosphate nor the lime had a pronounced influence on the percentage of phosphoric acid in the crop. In a number of cases the crop without phosphate showed as high or a higher percentage of phosphoric acid as the crop that received 1,000 pounds of superphosphate an acre.

### PHOSPHORIC ACID CONTENT OF GRAIN AND HAY IN FIELD EXPERIMENTS

In the nitrogen-availability field experiments which were started in 1908, certain plots receive no fertilizer, others receive superphosphate only, and others superphosphate and muriate of potash, and still others a complete fertilizer. Phosphoric acid has been determined in timothy hay and also in oats and wheat grain from certain of these plots, with the results shown in Table 8. It is at once apparent that the phosphorus treatment had little influence on the phosphoric acid in the timothy hay, and if averages be considered, about the same must be said of the oats and wheat grain. With the complete fertilizer (minerals and nitrate of soda), the oats grain shows a somewhat higher percentage of phosphoric acid than where no fertilizer is used, but the differences are not great.

TABLE 7.—*Phosphoric acid content (per cent) of barley grown on Colts Neck sandy loam under different phosphate treatments, 1923*

| Phosphate treatment (pounds per acre) | Phosphoric acid content (per cent) of barley grown— | | | |
|---|---|---|---|---|
| | With lime | | Without lime | |
| | Grain | Straw | Grain | Straw |
| **SUPERPHOSPHATE SECTION** | | | | |
| No phosphate | 0.895 | 0.187 | 0.843 | 0.135 |
| 100, superphosphate | .928 | .182 | .879 | .148 |
| 200, superphosphate | .861 | .156 | .910 | .156 |
| 500, superphosphate | .913 | .167 | .871 | .154 |
| 1,000, superphosphate | .890 | .153 | .879 | .130 |
| Average | .898 | .165 | .885 | .147 |
| **RAW ROCK PHOSPHATE SECTION** | | | | |
| No phosphate | 0.900 | 0.146 | 0.842 | 0.143 |
| 100, superphosphate | .923 | .180 | .861 | .130 |
| 200, superphosphate | .903 | .174 | .887 | .143 |
| 500 superphosphate | .918 | .172 | .920 | .128 |
| 1,000 superphosphate | .882 | .156 | .910 | .198 |
| Average | .907 | .171 | .895 | .150 |

TABLE 8.—*Phosphoric acid content (per cent) of grain and hay of various crops grown with different fertilizer treatments in a field experiment*

| Plot No. | Fertilizer treatment | Phosphoric acid content (per cent) of crops when grown— | | | | | |
|---|---|---|---|---|---|---|---|
| | | Without lime | | | With lime | | |
| | | Timothy hay, 1926 | Oats grain, 1929 | Wheat grain, 1930 | Timothy hay, 1926 | Oats grain, 1929 | Wheat grain, 1930 |
| 1 | No fertilizer | 0.494 | 1.226 | 1.278 | 0.454 | 1.289 | 1.232 |
| 2 | Muriate only | .482 | 1.151 | 1.267 | .436 | 1.186 | 1.220 |
| 3 | Superphosphate only | .517 | 1.128 | 1.082 | .494 | 1.295 | 1.249 |
| 4 | Minerals [a] | .505 | 1.128 | 1.130 | .540 | 1.283 | 1.284 |
| 9 | Minerals and nitrate of soda | .482 | 1.364 | 1.202 | .476 | 1.375 | 1.237 |

[a] Minerals = 320 pounds of superphosphate and 160 pounds of muriate of potash an acre.

PHOSPHORIC ACID CONTENT OF CORN (GRAIN) GROWN ON PLOTS RECEIVING DIFFERENT AMOUNTS OF A HIGH-ANALYSIS FERTILIZER IN FIELD EXPERIMENTS, 1930

The soil on which the corn used in the field experiment of 1930 was grown is a Sassafras loam of medium quality containing about 0.1 per cent phosphoric acid. It has been in corn continuously for several years, the respective plots receiving the same fertilizer treatment each year. The fertilizer analyzed 16 per cent ammonia, 18 per cent phosphoric acid, and 16 per cent potash. It was applied in the quantities indicated in Table 9. This table also reports the yield of dry shelled corn in pounds per acre, the percentage of phosphoric

acid in the grain, and the total amount of phosphoric acid removed by the crop.

It will be noted that there was a gradual increase in the yield as the fertilizer was increased. The 100-pound application of fertilizer gave only a slight increase in yield over the check and no increase in percentage of phosphoric acid. The 250-pound application gave a distinct increase in yield and also a distinct increase in percentage of phosphoric acid. The 500 and 1,000 pound applications likewise gave increases in yield and in percentage of phosphoric acid in the grain, the latter giving an increase over the check of nearly 40 per cent phosphoric acid. When 1,000 pounds of fertilizer were applied, there was about three times as much phosphoric acid removed in the grain as in that from the check plot.

TABLE 9.—*Phosphoric acid content of corn (grain) when grown with different quantities of a concentrated fertilizer in a field experiment, 1930*

| Plot No. | Fertilizer treatment | Yield of dry shelled corn | Phosphoric acid content | Total phosphoric acid removed from soil |
|---|---|---|---|---|
| | *Pounds per acre* | *Pounds* | *Per cent* | *Pounds* |
| 110 * | 0 | 1,050 | 1.053 | 11.06 |
| 111 | 100 | 1,067 | 1.047 | 11.17 |
| 112 | 250 | 1,474 | 1.249 | 18.41 |
| 113 | 500 | 1,544 | 1.370 | 21.15 |
| 114 | 1,000 | 2,151 | 1.457 | 31.34 |

* Check.

## THE EFFECT OF PHOSPHORIC ACID TREATMENT ON MIXED HERBAGE

Phosphoric acid was determined in samples of mixed herbage from plots that had received different fertilizer treatments. Dr. H. B. Sprague of the department of agronomy, who has been conducting this work, furnished the samples for these determinations and has kindly allowed the writers to use the data. The soil on which the plots are located is Chester stony loam. The fertilizers were applied in early April, and the pasture was clipped every two weeks. The samples from the different plots were composites of the different cuttings throughout the season and therefore do not represent the seasonal influence on the crop.

The results are shown in Table 10. In every case the grass from the phosphate-treated plots showed a higher percentage of phosphoric acid than did that from plots without phosphate treatment. While it is not safe to draw definite conclusions from so limited a number of determinations, the results do show a distinct increase in the phosphoric acid content of the hay where superphosphate was used. Doctor Sprague is of the opinion that these differences may be due largely to differences in the vegetation which resulted from the fertilizer treatment. He found, for example, more clover on the phosphate-treated plots than on those without phosphate.

This is a phase of the question which must be considered when dealing with mixed herbage. Also the influence of the time of cutting must not be overlooked. Reference has already been made to these points.

TABLE 10.—*The effects of phosphoric acid treatment and the application of other fertilizers upon the phosphoric acid content (per cent) of mixed herbage*

| No. | Treatment [a] | Percentage of phosphoric acid as $P_2O_5$ |
|---|---|---|
| 2 | Lime | 0.756 |
| 7 | Lime plus superphosphate | .952 |
| 10 | Lime plus muriate of potash | .704 |
| 11 | Lime plus muriate of potash plus superphosphate | .908 |
| 12 | Lime plus superphosphate plus muriate plus nitrate | .958 |
| 13 | None | .721 |
| 18 | Superphosphate | .940 |
| 21 | Muriate of potash | .687 |
| 22 | Superphosphate plus muriate of potash | .940 |
| 23 | Superphosphate plus muriate plus nitrate | .940 |
| | Average—Superphosphate | .955 |
| | Average—No superphosphate | .717 |

[a] Pounds per acre: Lime, 670; superphosphate, 600; muriate of potash, 100; and nitrate of soda, 100.

## INFLUENCE OF PHOSPHORIC ACID TREATMENT ON THE PHOSPHORUS CONTENT OF POTATOES AND YOUNG RYE

The soil for the experiment on potatoes and young rye is a Sassafras loam of fair quality. It contains 0.11 per cent phosphoric acid. The work was started in 1924, and the plots have received annual applications of fertilizer made so that the minimum application has been 1,600 pounds an acre. The minimum application of 16 per cent superphosphate has been 400 pounds an acre and the maximum 1,600 pounds. The treatments for the different plots are shown in Table 11.

TABLE 11.—*Treatment of plots used in potato and rye experiments*

| Plots (number) | Fertilizer mixture | | | Pounds of phosphoric acid applied per acre | Plots (number) | Fertilizer mixture | | | Pounds of phosphoric acid applied per acre |
|---|---|---|---|---|---|---|---|---|---|
| | N | $P_2O_5$ | $K_2O$ | | | N | $P_2O_5$ | $K_2O$ | |
| [a] 4 | 4 | 0 | 4 | 0 | 2 | 4 | 12 | 4 | 192 |
| 2 | 4 | 4 | 4 | 64 | 2 | 4 | 16 | 4 | 256 |
| 2 | 4 | 8 | 4 | 128 | | | | | |

[a] Checks.

Samples of potatoes from check plots and from those receiving the 4–16–4 fertilizer were analyzed for phosphoric acid in 1924 and in 1930. In 1924 the check plot gave 0.16 per cent phosphoric acid in the potatoes and the 4–16–4 plot also gave 0.16 per cent. In 1930 the check plot gave 0.14 per cent phosphoric acid in the potatoes, and the 4–16–4 plot 0.145 per cent.

Van Slyke[6] in his table of analyses of different crops gives 0.15 as the average percentage of phosphoric acid in potato tubers.

[6] VAN SLYKE, L. L. FERTILIZERS AND CROPS; OR, THE SCIENCE AND PRACTICE OF PLANT-FEEDING; A PRESENTATION OF FACTS, GIVING PRACTICAL METHODS FOR USING FERTILIZERS IN CROP GROWING, WITH SPECIAL EMPHASIS ON THE REASONS UNDERLYING THEIR USE, AND ON THE CONDITIONS OF THEIR GREATEST EFFICIENCY. p. 719. New York. 1912.

Not enough work has been done on potatoes from these plots to make the work conclusive, but it indicates that on a soil moderately supplied with phosphoric acid, applications of superphosphate do not materially influence the phosphoric acid content of the potato.

In the early fall of 1930, rye was seeded on the potato plots referred to above without any further fertilizer treatment, and on November 1, samples of the young rye were collected for phosphoric acid determinations. The results on the dry material are shown in Table 12.

TABLE 12.—*Phosphoric acid content (per cent) of young rye plants grown under different fertilizer treatments*

| Fertilizer mixture | | | Phosphoric acid in young rye | Fertilizer mixture | | | Phosphoric acid in young rye |
|---|---|---|---|---|---|---|---|
| N | $P_2O_5$ | $K_2O$ | | N | $P_2O_5$ | $K_2O$ | |
| 4 | 0 | 4 | 1.12 | 4 | 12 | 4 | 1.19 |
| 4 | 4 | 4 | 1.05 | 4 | 16 | 4 | 1.33 |
| 4 | 8 | 4 | 1.12 | | | | |

When the 4–4–4 and 4–8–4 fertilizer mixtures were used for the potatoes there was no increase in the percentage of phosphoric acid in the rye; when the 4–12–4 fertilizer mixture was used there was a small increase; and when the 4–16–4 fertilizer mixture was used there was an increase of slightly more than 18 per cent in the phosphoric acid content. It would seem reasonable to conclude that heavy applications of phosphoric acid would affect pasture grasses in very much the same way as it affected the young rye.

## SUMMARY

Tables are given showing the phosphoric acid content of a number of crops grown in cylinders and also on field plots where different fertilizer materials have been used and where different amounts of superphosphate have been applied over a period of years—in one case over a period of 30 years.

So far as the work reported is concerned, light applications of superphosphate—100 to 250 pounds an acre—did not, in most cases, materially influence the phosphoric acid content of the crop. With heavier applications—500 to 1,000 pounds an acre—there was usually some increase in the phosphoric acid content of the dry matter. In some cases the increase was as much as 40 per cent.

In the case of potatoes, increasing the amount of superphosphate applied seemed to have no influence on the phosphoric acid content of the crop.

Phosphoric acid determinations were made on a limited number of samples of mixed herbage from plots with and without phosphate. The results indicate that the phosphate treatment tends to increase the percentage of phosphoric acid in the hay. However, attention is called to the fact that such increases may be due to changes in the type of vegetation which the phosphate treatment causes rather than actual increase in a specific plant.

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Undoubtedly there may be conditions in which it would be profitable to apply rather large quantities of superphosphate for the purpose of increasing the phosphoric acid content of the dry matter.

The soils used in these experiments varied in phosphoric acid content from 0.1 to 0.8 per cent, but the phosphoric acid content of the soil evidently had little or no influence on the phosphoric acid content of the crop, since soybeans grown on Colts Neck loam containing 0.8 per cent $P_2O_5$ contained no more phosphoric acid than did those grown on Sassafras loam with about 0.1 per cent $P_2O_5$.

In comparison with the changes that may be wrought in the nitrogen content of plants by the application of nitrogenous fertilizers, the changes in phosphorus content produced by phosphate treatments are relatively small.

# VITAMIN A AND PROTEIN CONTENT OF VARIOUS FISH MEALS[1]

By L. A. MAYNARD, *Professor of Animal Husbandry*, R. C. BENDER, *Analyst*, and C. M. MCCAY, *Research Assistant Professor of Animal Husbandry, Animal Husbandry Department, Cornell University Agricultural Experiment Station*

## INTRODUCTION

Although fish meals are derived from widely different sources of natural supply and are subject to very different methods of treatment before being placed on the market, they are usually classed by the stockman who employs them in animal feeding merely as fish meal. On the assumption that these products, differing in origin and in method of manufacture, might also differ in nutritive value, an investigation was undertaken to ascertain whether there are any important nutritive differences among the products which are popularly known under the general term "fish meal." This investigation has been in progress for three years, and the results so far obtained are here reported.

## DESCRIPTION OF FISH MEALS USED

During the course of the investigation seven different fish meals have been employed. For convenience of reference these products are listed in Table 1, with certain data as to their sources and the methods of their manufacture. White fish meal is made from non-oily fish, principally cod and haddock, and consists of the heads, tails, fins, backbones, and the flesh remaining from the cutting of the fillets. The entrails are removed at sea and thus are not included. The material is cooked and then dried. The three products used were all vacuum dried at low temperatures, as shown in the table. The menhaden is an oily fish, and the meal is the residue after the removal of a portion of the oil by pressing and cooking. The dried product still contains from 4 to 12 per cent of oil. The higher values are found in meals containing unpressed fish from catches too low in oil to warrant pressing. Most of the menhaden meal now on the market is flame dried at a high temperature, as were two of the products studied. The third product listed was a steam-dried meal produced experimentally by the Bureau of Fisheries, as described by Harrison (*6*).[2]

TABLE 1.—*Fish meals used during the investigation*

| Meal | Parts of fish included | Method of drying |
|---|---|---|
| White, No. 1 | Entire fish less side meat (fillets), less entrails | Vacuum dried under 105° F. |
| White, No. 2 | do | Vacuum dried at about 116° F. |
| White, No. 3 | do | Vacuum dried at about 100° F. |
| Menhaden, No. 1 | Entire fish less a portion of the oil | Flame dried at 500°–600° F. |
| Menhaden, No. 2 | do | Flame dried at 500°–600° F. |
| Menhaden, No. 3 | do | Steam dried at 120°–200° F. |
| Pilchard | do | Indirect-heat dried at 300°–400° F. |

[1] Received for publication Dec. 4, 1931; issued May, 1932.
[2] Reference is made by number (italic) to Literature Cited, p. 603.

Pilchard meal consists of whole sardines from which a portion of the oil may have been extracted, and of heads, tails, and entrails resulting as a by-product from the canning of sardines. In analysis the product is similar to menhaden meal.

The drying temperatures shown in Table 1 are based upon information from the manufacturers. Some of the products were undoubtedly subjected to higher initial temperatures than those shown. No information is available as to the time factors involved. For a detailed discussion of the methods of preparation of various fish meals the reader is referred to the reports by Harrison (*6*) and Fiedler (*5*).

## PRELIMINARY GROWTH STUDIES

Two preliminary experiments were carried out in 1928–29, which were expected to give general information only, as a basis for planning more specific studies. These experiments are reported briefly with summarized results.

First a study was made in which a diet of 92 parts of yellow corn and 8 parts of white meal No. 1 was compared with a combination of 90 parts of corn and 10 parts of tankage. Both diets contained approximately 13.5 per cent of protein. Twelve male rats were placed upon each diet shortly after being weaned, and growth records were kept for 16 weeks. The data are presented in a condensed form in Table 2. They indicate that the diet containing fish meal was superior to the tankage combination. This result is in accord with the observations of other investigators, as recently reviewed by Manning (*10*).

TABLE 2.—*Growth of 12 male rats on a diet of corn and fish meal as compared with growth of 12 male rats on a diet of corn and tankage*

| Diet | Average weight of rats at start | Average gain in weight during 6 weeks | Average gain in weight during 16 weeks |
|---|---|---|---|
| | *Grams* | *Grams* | *Grams* |
| Corn and white meal No. 2 | 46 | 129±3 | 229±5 |
| Corn and tankage | 47 | 86±5 | 160±6 |

A survey experiment was next carried out in which six different fish meals were studied. The essential data are shown in Table 3. In the first five diets corn and fish meal were combined in the proportion 90 to 10. In diet No. 6, 89 parts of corn to 11 of tankage were used. The six diets are similar in protein content, as shown by the percentage figures which are based on an analysis of the fish meals used and the average figure of 9.3 per cent for corn. Diet No. 7 is the same corn and tankage combination used in diet No. 6 plus 0.5 of yeast and 3 drops of cod-liver oil daily per rat. These additions were made in view of the poorer results obtained with tankage in the first experiment to ascertain whether they were due to vitamin deficiencies. Diets Nos. 8 and 9 were used to compare the two combinations at a lower protein level.

TABLE 3.—*Growth of male and female rats when fed various fish meals, or tankage and supplements, combined with corn*

| Diet | | | Animals | | Average weight at start | | Average gain in 10 weeks | |
|---|---|---|---|---|---|---|---|---|
| No. | Ingredients | Protein content | Males | Females | Males | Females | Males | Females |
| | | *Per cent* | *Number* | *Number* | *Grams* | *Grams* | *Grams* | *Grams* |
| 1 | Corn and white meal No. 1 | 14.4 | 5 | 5 | 53 | 58 | 215±8 | 128±4 |
| 2 | Corn and white meal No. 2 | 14.8 | 5 | 5 | 58 | 56 | 237±9 | 147±3 |
| 3 | Corn and white meal No. 3 | 14.6 | 5 | 5 | 62 | 46 | 217±8 | 135±5 |
| 4 | Corn and menhaden meal | 14.3 | 5 | 5 | 55 | 59 | 196±5 | 141±6 |
| 5 | Corn and pilchard meal | 14.3 | 5 | 5 | 57 | 58 | 153±6 | 118±7 |
| 6 | Corn and tankage | 14.5 | 5 | 5 | 53 | 56 | 177±8 | 117±4 |
| 7 | Corn and tankage plus yeast and cod-liver oil | 14.5 | 5 | 5 | 52 | 56 | 221±5 | 125±4 |
| 8 | Corn and white meal No. 1 | 11.5 | 5 | 5 | 56 | 49 | 153±6 | 119±6 |
| 9 | Corn and tankage | 11.5 | 5 | 5 | 52 | 55 | 102±7 | 94±4 |

It is noted in Table 3 that five male and five female rats were used with each diet. Because of their different growth rates the data for the two sexes are averaged separately. Since the males grew faster, their quantitative requirements for the various nutritive factors exceed those of females, and thus growth experiments with males constitute a more rigid test.

From a study of the data for average gain in 10 weeks on the first six diets, it is seen that in general the white meals gave better results than the other supplements. Considering odds of 30:1 as practical certainty, the results with the males show each cod and haddock meal significantly superior to tankage. Numerically superior results are shown in each comparison for the females also, and in the case of white meal No 2 the difference is clearly significant. At the lower level of protein intake (diets Nos. 8 and 9) significantly better results are shown for white meal No. 1 in the case of both sexes. On the basis of the results with males each white meal proved significantly superior to pilchard meal. The results with females are numerically superior in the case of the white meals. Menhaden is shown to be superior to pilchard—numerically for females, significantly for males. White meal No. 2 gave significantly better results than menhaden meal in the case of the males, and numerically so in the comparison with females. The results with diets Nos. 6 and 7 show that at least one of the limiting factors in the corn and tankage diet was its vitamin content.

The results set forth in Table 3 clearly indicated that marked nutritive differences exist among certain of the products studied but furnished no definite information as to their nature. Therefore, more specific studies were undertaken.

## VITAMIN A STUDIES

It was recognized that differences between oily and nonoily fish and differences as regards heat treatment in drying might be expected to result in meals varying markedly in vitamin A content. It was decided to study this question by a comparison of the vacuum-dried white meal with the menhaden meal dried at a much higher temperature. The analyses of the meals used in these and succeeding studies are given in Table 4.

TABLE 4.—*Percentage composition of white and menhaden fish meals*

| Meal | Water | Ash | Protein | Fat |
|---|---|---|---|---|
| White, No. 1 | 9.7 | 19.01 | 64.08 | 2.60 |
| Menhaden, No. 1 | 5.49 | 21.60 | 59.56 | 7.21 |
| Menhaden, No. 2 | 5.19 | 21.03 | 60.82 | 6.14 |
| Menhaden, No. 3 | 7.00 | 16.50 | 59.68 | 11.83 |

In the first experiment the white meal and menhaden meals Nos. 1 and 2 were used. They were fed as diets Nos. 10, 11, and 12, shown in Table 5. It is noted that the diets were made up in such a way as to provide substantially the same percentage of protein and the same calorific value in each. Dried yeast was added to provide the vitamin B complex. Irradiated ergosterol was fed separately to provide vitamin D.

TABLE 5.—*Composition of diets used in vitamin A experiments*

| Ingredients | Composition of diet No.[a]— | | | |
|---|---|---|---|---|
| | 10 | 11 | 12 | 13 |
| White meal No. 1 ..... parts | 19.0 | | | |
| Menhaden meal No. 1 ..... do | | 20 | | |
| Menhaden meal No. 2 ..... do | | | 20 | |
| Menhaden meal No. 3 ..... do | | | | 20 |
| Lard ..... do | 20.5 | 20 | 20 | 19 |
| Sugar ..... do | 10 | 10 | 10 | 10 |
| Cooked starch ..... do | 45.5 | 45 | 45 | 46 |
| Yeast ..... do | 5 | 5 | 5 | 5 |
| Protein ..... per cent | 14.38 | 14.51 | 14.77 | 14.53 |

[a] In addition to the above each rat received 0.001 mg of irradiated ergosterol daily.

Ten male rats were placed on each diet shortly after being weaned and were fed for a period of eight weeks. The growth data are shown in Figure 1, A. The broken curve represents the normal growth of the colony. The experimental growth curves are plotted from the average weekly weights of the 10 rats. It is noted that the rats on the white meal made practically normal growth. No signs of xerophthalmia developed in the 8-week experimental period. On the other hand, the growth on the other two diets became progressively poorer as the experiment continued, and the total growth reached at the end of eight weeks was less than half that produced on diet No. 10. On diet No. 11 the first case of xerophthalmia appeared during the sixth week. During the next week the trouble developed in seven other rats, and the total cases reached eight during the last week. None of these eight rats made any gain during this last week, and some of them lost weight. The small increase for the group as shown in Figure 1, A, was due entirely to the two rats which thus far showed no signs of xerophthalmia. The history of the development of this eye trouble was similar with diet No. 12. At the close of the experiment only one rat failed to show symptoms of the disease, and two had already died from it.

The rats were allowed to feed ad libitum, but food-intake records were kept during the first two weeks and again during the seventh week. During the first two weeks all the diets were consumed in

liberal and in nearly the same quantities, indicating that failure to eat was not the primary cause of the poorer growth on diets Nos. 11 and 12. During the seventh week, despite their very slow growth, the rats on diets Nos. 11 and 12 were eating 15 to 25 per cent more food per unit of body weight than those on diet No. 10, quantities markedly in excess of their maintenance requirements.

This vitamin A experiment was repeated, the same diets, Nos. 10 and 12, being used, as shown in Table 5, and also diet, No. 13, containing the steam-dried menhaden meal. Ten rats were given each ration. The growth data are shown in Figure 1, B. Again the rats on the white-meal diet grew practically normally during the experimental period and no xerophthalmia developed, a marked contrast to the performance on the menhaden diets. Apparently the rats used in this second experiment had less reserve vitamin A in their bodies

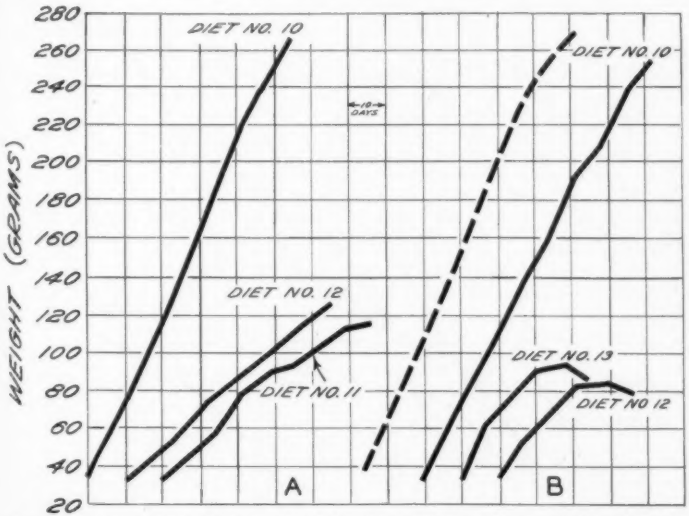


FIGURE 1.—Growth of rats during the first (A) and second (B) experiments carried on to determine the vitamin A content of fish meals. The broken line represents normal growth in the colony. See Table 5 for composition of rations

at the start, for the xerophthalmia developed earlier on diet 12 than it did in the first experiment. At the close of the fifth week all the rats on diets Nos. 12 and 13 exhibited the disease, and all except two (on diet No. 12) were losing weight. Thus these groups were discontinued at this time. It is seen in the chart that the rats on the steam-dried menhaden meal (diet No. 13) grew no better than those on the flame-dried product (diet No. 12). At the close of the five weeks all of them contracted xerophthalmia and all were losing weight.

In order to make certain that failure to consume as much of the menhaden meals was not responsible for the poor results with them, a further comparison of the white meal and the steam-dried menhaden was made by the curative method. After the growth of the experimental animals had ceased upon a vitamin-A-free diet the meals were added at the rate of 1 g per rat per day. The results of this test are

shown in Figure 2. It is shown that the white fish meal caused a resumption of growth nearly comparable to that of the butter, while the steam-dried menhaden was ineffective, and that the animals continued to lose weight and died as did the controls. With the white meal the xerophthalmia was cured, while with the menhaden it became progressively worse until death.

It is clear from these three experiments that the vacuum-dried white meal proved markedly superior to the flame-dried and steam-dried menhaden meals in vitamin A content. It was rather surprising to find the white meal so effective in view of its low oil content, and of the further fact that the oil present is presumably a body oil. Haddock oil, which probably makes up a considerable proportion of the oil present, is certainly not rich in vitamin A, according

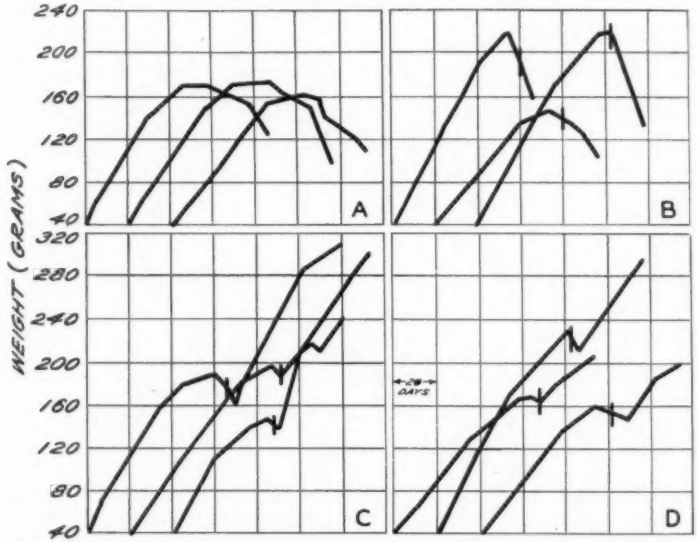


FIGURE 2.—Growth of rats when fed butter and fish meals as a source of vitamin A: A, Control; B, menhaden meal; C, butter; D, white meal. Vertical lines indicate points at which supplements were added to the basic ration

to the work of Kik and McCollum (*9*). Bohstedt and coworkers (*3*) have shown menhaden meal, presumably a flame-dried product, to be lacking in vitamin A. Whether the poor results obtained with the menhaden products were due to the destructive action of the drying process or to a low vitamin A content in the raw material is not brought out by these experiments. Earlier experiments by Maynard and Miller (*11*) showed that menhaden oil contains vitamin A in limited amounts.

## PROTEIN STUDIES

A study of the nutritive value of the proteins of representative fish meals was next undertaken. White meal No. 1 and menhaden meals Nos. 2 and 3 were used. The first experiment consisted of a comparison of groups of nine rats each given access at all times to

diets containing these meals. The diets were made up to supply a level of 7 per cent of protein calories. These diets are shown in Table 6. The experiment lasted nine weeks, and the growth records are presented in Figure 3. It is noted in Figure 3 that the best growth was made on the white meal (diet No. 17) and the poorest on the flame-dried menhaden (diet No. 18), the steam-dried product (diet No. 19) occupying an intermediate position.

TABLE 6.—*Composition of diets fed in protein experiment in which the group-feeding method was used*

| Ingredients | | Composition of diet No.[a]— | | |
|---|---|---|---|---|
| | | 17 | 18 | 19 |
| White meal | parts | 12.9 | | |
| Flame-dried menhaden meal | do | | 13.8 | |
| Steam-dried menhaden meal | do | | | 13.5 |
| Lard | do | 19.7 | 19.2 | 18.5 |
| Sugar | do | 10.0 | 10.0 | 10.0 |
| Cooked starch | do | 55.4 | 55.0 | 56.0 |
| Salt mixture | do | 2.0 | 2.0 | 2.0 |
| Protein | per cent | 8.3 | 8.2 | 8.1 |
| Energy per gram | calories | 4.74 | 4.69 | 4.74 |
| Protein calories | per cent | 7.0 | 6.9 | 7.0 |

[a] In addition to the above each rat received 200 mg of yeast and 3 drops of cod-liver oil daily.

These results were considered as suggestive only, and a second experiment was conducted in which individual food records were kept. The rations used are shown in Table 7. In this experiment a higher protein level was used than in the first experiment; also more starch and less lard were included.

TABLE 7.—*Composition of diets fed in protein experiment in which the limited-individual feeding method was used*

| Ingredients | | Composition of diet No.[a]— | | |
|---|---|---|---|---|
| | | 20 | 21 | 23 |
| White meal | parts | 14.7 | | |
| Flame-dried menhaden meal | do | | 15.3 | |
| Steam-dried menhaden meal | do | | | 15.6 |
| Lard | do | 15.5 | 14.9 | 14.0 |
| Sugar | do | 10.0 | 10.0 | 10.0 |
| Cooked starch | do | 58.8 | 58.8 | 59.4 |
| Salt mixture | do | 1.0 | 1.0 | 1.0 |
| Protein | per cent | 9.3 | 9.3 | 9.3 |
| Energy per gram | calories | 4.42 | 4.41 | 4.45 |
| Protein calories | per cent | 8.6 | 8.6 | 8.6 |

[a] In addition to the above each rat received 200 mg of yeast and 3 drops of cod-liver oil daily.

The second experiment was conducted in accordance with a modification of the paired-feeding method. The available animals were divided into groups of three, the animals comprising a given trio, being as nearly alike as possible. Six groups were selected in this way. One animal from each trio was placed on each of the three rations. For a given trio the food intake was governed by the animal consuming the least, but as a given animal attained a greater weight than the animal regulating the food intake of the group, it was fed additional rations to enable it to meet its higher maintenance require-

ment. This procedure, which differs from the absolute equalization of food used by Mitchell in his paired-feeding experiments, requires explanation.

The argument for the absolute equalization of food in the paired-feeding method is that if one is superior to another for growth its superiority should be evident at equal levels of food intake. However, as the animal on the superior ration increases in weight over its mate its maintenance requirement becomes greater than that of its mate. Under these conditions an equal food intake for both means that the larger animal must be using a larger proportion for maintenance, and less remains for growth promotion. Under these conditions an absolute equality of food intake means that the quantities available for the specific function which is being used as the criterion in comparing the two rations are not equal. The faster-growing animal is penalized. It may be accepted that if a given ration continues to produce superior growth under these conditions, the conclusion that it is superior is made stronger thereby. However, the data would seem less useful for a quantitative comparison, and an opposite result might make the interpretation less clear. At least, it would seem theoretically sound in using growth as the measure to endeavor to equalize the food available for this function.

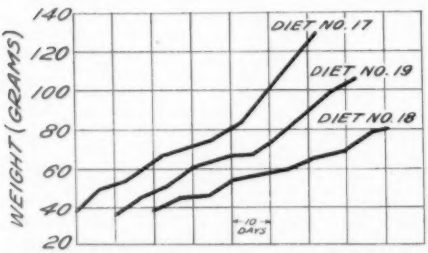


FIGURE 3.—Growth of rats when allowed unrestricted access to fish meals as a source of protein, at a level of 7 per cent of protein calories. See Table 6 for composition of rations

In 1916 Osborne and Mendel (*15*) compared the efficiency of various proteins in inducing growth, keeping the food intakes the same for the different rations. In their discussion they state (*15, p. 4*):

> * * * inasmuch as the animals were all receiving the same absolute amounts of food on the corresponding day of each period, the rapidly growing animals were actually put *at a disadvantage* in having a smaller allowance of food *per unit of body weight* * * *.

Armsby (*1*), in his plan for studies of the growth of calves by means of paired-feeding experiments, specified that the ration should be adjusted in accordance with the increasing live weight of the animal, but that the energy supply of both animals of a pair should be kept the same per 1,000 pounds of live weight. In discussing the paired-feeding method, Mitchell and Beadles (*12, p. 227*) state:

> If one ration is superior to another in the support of an animal function such as growth, its superiority should be evident when the intakes of both rations by comparable animals is the same, either absolutely or in proportion to some determinant of food requirements, such as body weight, or a mathematical function of body weight.

In comparing rations for milk production it is standard practice to provide for the different maintenance requirements of the animals first and then to equalize the intakes in terms of the function being studied.

In view of these various considerations it seemed worth while to try out a procedure which would involve such adjustments for differ-

ences in maintenance requirements as would provide each pair with an equal food intake for growth. In order to do this it was obviously necessary to have values for the maintenance requirements of rats of different weights. The values used by the writers were worked out from data by Osborne and Mendel (*14*). These investigators present the intakes of a purified diet by rats of different weights receiving just enough food to hold them at nearly constant weight for periods of three weeks. From their data it was possible to calculate the calories required per week per gram of rat for maintenance. On the basis of the caloric value of 4.45 (the highest one shown in Table 7), it was calculated that the following quantities of the diets used in the experiments here described would be required for maintenance at the different weights:

| Weight of rat in grams | Grams of diet required for maintenance per gram of rat per week |
|---|---|
| 50–75 | 0.50 |
| 75–100 | .46 |
| 100–125 | .36 |
| 125–150 | .36 |
| 150–175 | .35 |

It is recognized that the calculation of these values involved certain assumptions. There is an experiment in progress in this laboratory by McCay and Crowell which is furnishing very complete data regarding the maintenance requirements of rats. On the basis of calculations from the data available to date, namely, for rats of various weights up to 100 g, the requirements have been found to be approximately 10 to 15 per cent less than those represented by the data in the preceding table. The results of this study now in progress suggests that the maintenance allowances used in these experiments were somewhat too high. The bearing of this upon the results of the experimentation will be referred to later.

During the first two weeks of this experiment each rat of a given trio was fed the same quantity of food, governed by the consumption of the animal eating the least. At the close of this period, in each trio the rat that was consuming the least weighed markedly less than the other two. From this time on the two heavier rats of the trio were given additional food to provide for their extra maintenance needs. For example, rat 19 of trio 1 (Table 8) weighed 64 g at the end of the two weeks, while rat 18 weighed 80 g and rat 32 weighed 86 g. Since rat 18 was 16 g heavier than rat 19, it required $16 \times 0.46$, or 7.4 g additional food a week for maintenance, on the basis of the requirement for rats weighing 75–100 g previously listed. Similarly, rat 32 required 10.1 g additional. During the following week these amounts were allowed the rats in question in addition to the amount consumed by rat 19. At the close of the third week similar calculations were made, and so on for each trio to the close of the experiment.

The food intakes and the growth records are presented in Table 8. These records cover an experimental period of nine weeks. In trio 6 the rat on the steam-dried menhaden died from an accident during the fourth week, and thus the records are presented for the other two only. In comparing the gains made it is seen that in all six comparisons the rat receiving the white meal made a larger gain than its mate on flame-dried menhaden meal. An analysis of these

data by Student's methods shows that the odds favoring the white meal are greater than 3,000:1. The white meal is also shown superior to the steam-dried menhaden in the five comparisons made. A statistical analysis shows that the odds are 356:1 in favor of the white meal.

TABLE 8.—*Growth and food records (grams) of rats during a 9-week protein experiment in which the limited-individual-feeding method was used*

| Item | Growth and food consumption data for rats in— | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Trio 1, rat No.— | | | Trio 2, rat No.— | | | Trio 3, rat No.— | | |
| | 19 on flame-dried menhaden meal | 18 on steam-dried menhaden meal | 32 on white fish meal | 30 on flame-dried menhaden meal | 31 on steam-dried menhaden meal | 28 on white fish meal | 275 on flame-dried menhaden meal | 276 on steam-dried menhaden meal | 277 on white fish meal |
| Initial weight | 39 | 41 | 39 | 44 | 47 | 45 | 39 | 37 | 35 |
| Final weight | 112 | 161 | 178 | 123 | 159 | 215 | 92 | 156 | 180 |
| Gain | 73 | 120 | 139 | 79 | 112 | 170 | 53 | 119 | 145 |
| Basal food intake | 414 | 417 | 413 | 477 | 477 | 480 | 380 | 382 | 384 |
| Extra food for maintenance | 0 | 88 | 104 | 0 | 40 | 93 | 0 | 89 | 129 |
| Total | 414 | 505 | 517 | 477 | 517 | 573 | 380 | 471 | 513 |
| Gain per gram of basal food | .18 | .29 | .34 | .17 | .24 | .35 | .14 | .31 | .38 |
| Gain per gram of total food | .18 | .24 | .27 | .17 | .22 | .30 | .14 | .25 | .28 |

| Item | Growth and food consumption data for rats in— | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Trio 4, rat No.— | | | Trio 5, rat No.— | | | Trio 6, rat No.— | | |
| | 10 on flame-dried menhaden meal | 16 on steam-dried menhaden meal | 11 on white fish meal | 24 on flame-dried menhaden meal | 25 on steam-dried menhaden meal | 26 on white fish meal | 12 on flame-dried menhaden meal | 13 on steam-dried menhaden meal | 17 on white fish meal |
| Initial weight | 36 | 40 | 41 | 34 | 32 | 34 | 35 | (a) | 31 |
| Final weight | 111 | 144 | 182 | 116 | 108 | 154 | 93 | (a) | 156 |
| Gain | 75 | 104 | 141 | 82 | 76 | 120 | 58 | (a) | 125 |
| Basal food intake | 431 | 431 | 431 | 413 | 411 | 414 | 388 | ..... | 389 |
| Extra food for maintenance | 0 | 66 | 119 | 33 | 0 | 96 | 0 | ..... | 81 |
| Total | 431 | 497 | 550 | 446 | 411 | 510 | 388 | ..... | 470 |
| Gain per gram of basal food | .17 | .24 | .33 | .20 | .18 | .29 | .15 | ..... | .32 |
| Gain per gram of total food | .17 | .21 | .26 | .18 | .18 | .24 | .15 | ..... | .27 |

[a] Died accidentally.

A comparison of the data for steamed menhaden with those for flame-dried menhaden shows that greater gains were made on the former in four of the five comparisons. It is sometimes considered that with five pairs the results with every pair should favor a given ration if they are to be considered significant in demonstrating the superiority of the ration. However, such a criterion does not take full advantage of the data in the present comparison. In the four pairs in which the steam-dried meal proved superior the differences in gains range from 29 to 66 g, the mean being 44 g, while in the one

pair giving contrary results the difference in favor of the flame-dried product was only 6 g. An analysis of the data for the five pairs by Student's method reveals odds of 40:1 favoring the steam-dried meal. It seems highly probable, therefore, that the results demonstrate its superiority, despite the erratic results from the comparison in trio 5.

For each trio the food-intake data are divided into a basal intake, which was governed by the amount eaten by the animal consuming the least, and an extra allowance for maintenance, which was given the faster-growing rats, based on their increased weight as previously described. Assuming that the extra allowances for maintenance were actually needed for this purpose, the gains per gram of basal food could be considered quantitative measures of the relative efficiences of the different meals as sources of protein for growth. However, as has been stated, experiments in progress indicate that the maintenance allowances were somewhat excessive. This would serve to give the faster-growing and thus heavier animals an advantage as regards food available for growth. Thus the differences in protein efficiency can not be considered as large as the differences in gain per unit of basal food would suggest. As a further measure, the gain per gram of total food is shown. It is noted that without exception the white meal proved superior to both the menhaden meals in this respect and that the steam-dried menhaden proved superior to the flame-dried in four out of five cases and equal in the other.

The method here used of allowing additional food in accordance with higher maintenance needs worked out satisfactorily in the present instance and is believed to be worthy of further trial. It seems theoretically sound, provided the experimenter has data as to maintenance requirements applicable to the conditions in his colony. Perhaps some of the published data on the basal metabolism of the rat could be adapted for the purpose. Whatever data are used, it is evident from the studies of Benedict and MacLeod (*2*) on the heat production of the rat that account must be taken of environmental temperature.

As a result of the trial here reported, certain possible difficulties in carrying out the method can be foreseen. The use of trios instead of pairs may present certain difficulties even where the food intakes are absolutely equalized, and it is believed that the use of the present method should be limited to pairs. Even here one can forsee the possibility that the rat consuming the least might be the heavier if its ration was much more efficient but much less palatable. Under these conditions, with the basal intake being governed by the heavier animal, an additional amount for maintenance figured for the latter would of course not be consumed. The only practical way would be to decrease the food given the lighter by the amount in question. Again with the usual situation of the lighter rat consuming the least, the appetite of its mate might not at all times prove sufficiently greater to cause it to consume completely its additional allowance for maintenance. Even if either of these possibilities happened only in an occasional week, it would serve to complicate the working out of the method. None of these possible complications were encountered in the present experiment. Further trials of it are needed to show whether they are likely to happen with sufficient frequency to make the method impracticable.

This second protein experiment checks the first one in showing that the protein of the vacuum-dried white fish meal is superior to that of the menhaden meals. It seems probable that the differences in heat treatment are primarily responsible for these differences. In fact, since the menhaden meal contains the entire fish, including the entrails, while the white meal consists of residues from the cutting of fillets and does not contain any entrails, one would rather expect any difference in the raw material to be in favor of the menhaden. On the other hand, Ingvaldsen (*7*) has shown in his nitrogen-partition studies that high temperatures have a detrimental effect upon protein quality. This investigator found that temperatures above 195° C. reduce certain essential amino acids, and he concluded that the biological value must be lessened thereby. Morgan (*13*) has reported that the protein of cereals subjected to dry heat or toasting at approximately 200° for 45 minutes is not well utilized for growth. The differences in heat treatment shown in Table 1 may be sufficient to explain the differences in protein efficiency found for the products studied in this experiment. Ingvaldsen (*8*) found that putrefaction also had a deleterious influence, a fact which may be a further explanation of the poorer results obtained with the flame-dried menhaden. It is recognized that putrefaction occurs to a certain extent in the course of the handling of the material before it is dried, in the case of some of the commercial products at least.

Evidence that the heat treatment is the primary factor concerned in the differences in the protein efficiency of fish meals is furnished by Daniel and McCollum (*4*). From a comparison of various fish meals on the basis of protein content, it is reported that vacuum-dried meals are superior to flame-dried meals and that vacuum-dried cod and menhaden meals are similar in feeding quality. Another finding of these investigators, which, however, is not in agreement with the results here reported, is that a steam-dried menhaden meal is equal or superior to a vacuum-dried white fish meal. On the basis of the analytical figures given, it is evident that a different white meal from the one employed in these experiments was used. It is possible that marked differences exist in the vacuum-dried white products on the market. From a practical standpoint further carefully controlled comparisons of the various commercial vacuum-dried products are needed, not only to ascertain whether there are marked differences among them, but also to ascertain how uniform the product of a given manufacturer is.

A continuation of the protein studies in this laboratory, by the nitrogen-balance method, has resulted in more specific information, which is reported by Schneider (*16*).

## SUMMARY

Seven different fish meals, five of them commercial products sold for animal feeding, have been studied in growth experiments with rats. A preliminary experiment revealed marked differences among certain of the commercial products when fed as supplements to cornmeal, although all except one gave better results than tankage. Vitamin A experiments showed a vaccum-dried white fish meal to be a good source of this vitamin, in contrast to a steam-dried and to flame-dried menhaden meals which proved to be lacking in it. The vacuum-dried white meal was found to be superior to the steam-dried

menhaden and the latter superior to a flame-dried menhaden as regards protein efficiency for growth. The results suggest that differences in heat treatment are at least partially responsible for the nutritive differences found.

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